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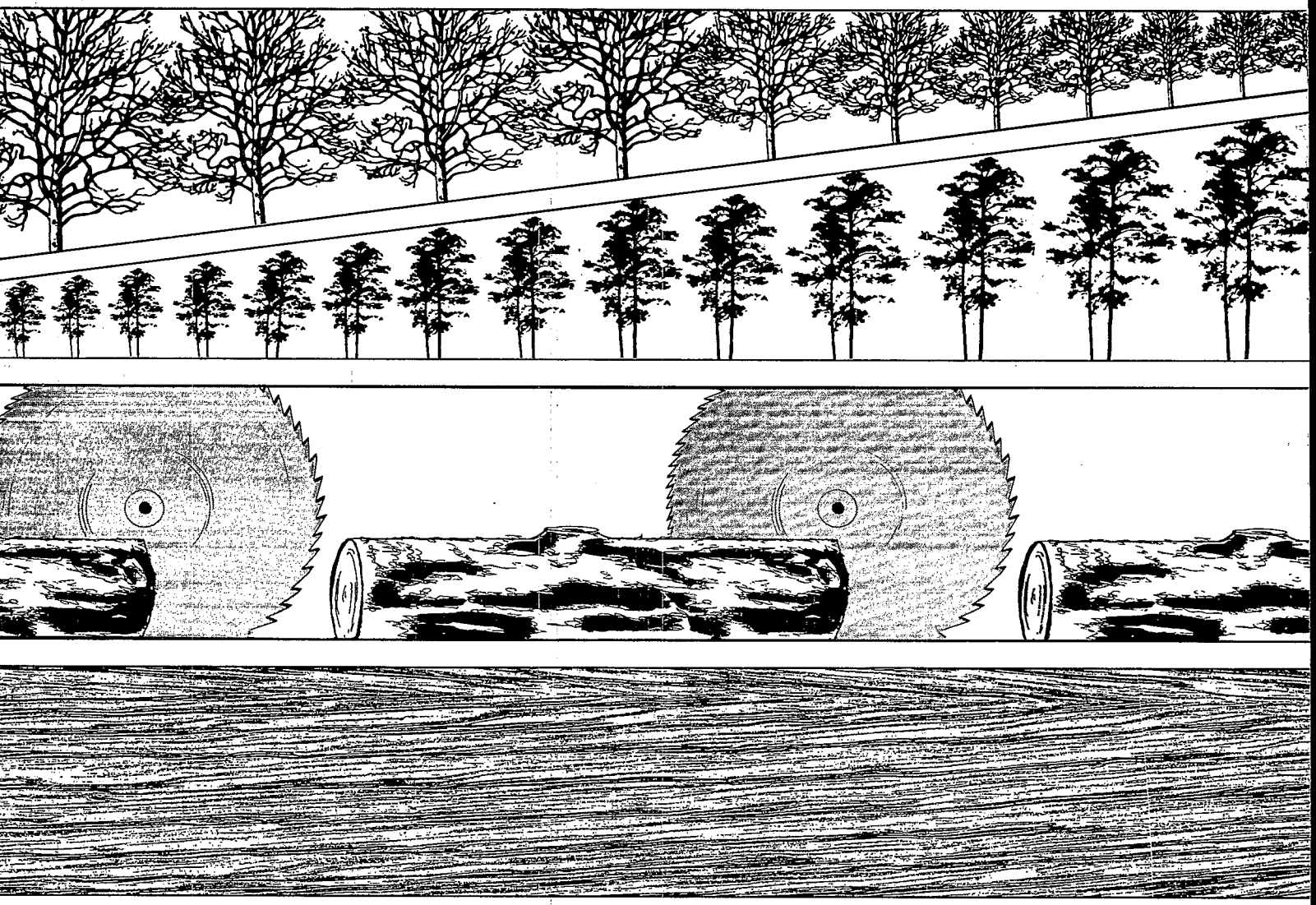
Seminar Publication

Pollution Control in the Forest Products Industry



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Pollution Control in the Forest Products Industry

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The information in this publication was prepared by the following:

James L. Veatch, Attorney, Legal Branch, Enforcement Division, U.S. EPA Region VI; David C. Bray, Technical Advisor, Air Programs, U.S. EPA Region X, James H. Himel, Rudolph H. Moyer, and Jonathan D. Cook, GEOMET, Inc.; John W. Robinson, Manager Environmental Services, Kirby Lumber Corporation; David C. Junge, Ph.D., Department of Mechanical Engineering, Oregon State University; Michael W. Guidon, Process Engineer, Georgia-Pacific Corporation; Allan H. Mick, Senior Environmental Engineer, Georgia-Pacific Corporation; Gary Grimes, Environmental Coordinator, SWF Plywood Company; and Clifford T. McConnell, President, McConnell Industries, Inc.

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Introduction
Air Pollution Control

The forest products industry manages some of the nation's most pristine land areas. At the same time, the industry depends heavily on organic fuels—especially wood waste—for energy needed to manufacture its products. These manufacturing processes represent a highly visible single influence on the air quality of the regions in which they are located. Air quality standards affecting the industry are strict, and in many cases they are becoming stricter as the States and Federal government actively pursue the goals of the Clean Air Act.

This publication first briefly reviews the Clean Air Act as it applies to the forest products industry. Also presented are examples of the kinds of research and technologies being applied by the industry to meet its air pollution control responsibilities.

The information presented here has been assembled from seminar proceedings. As such, this publication does not prescribe how individual members of the forest industry can meet their specific air pollution control requirements, but rather offers a perspective on some of the issues and technologies associated with up-to-date air quality management, as seen by industry members, researchers, and regulatory officials.

The forest products industry and State and Federal regulatory agencies face the same air quality challenge, which involves technology, policy, and the economy. The demand for wood-based products is rising sharply. At the same time, air quality standards being faced by industry are tightening. Where clean air already exists, nondegradation is a key goal. Where national air quality standards are not currently being attained, improvements are mandated. Compliance programs must balance concerns for clean air with concerns for the industry's ability to produce competitively an affordable product, one that plays a vital role in the nation's economic growth.

This publication is part of a communication process intended to foster a cooperative effort in administering and implementing necessary air pollution control programs. Additional reading materials relating to the subjects covered in this publication are listed in the Appendix.

Chapter 2

The Clean Air Act

Background

The Clean Air Act in its present format, amended 1977, has as its origin the Clean Air Act of 1970. At that time Congress established the basic programs and philosophies that are in effect today. These programs generally can be broken down into three areas: (1) the attainment and maintenance of National Ambient Air Quality Standards (NAAQS), (2) limitations on the emissions of certain pollutants from stationary and mobile sources, and (3) a permit program for new sources. In conjunction with these programs, Congress established some statutory deadlines for such things as attainment of the NAAQS and emission levels for new automobiles.

The primary responsibility for implementing these and most other requirements of the Clean Air Act belongs to the individual states. The strategy and mechanism for accomplishing this is the State Implementation Plan (SIP), containing regulations and procedures developed by each state and approved by EPA for implementing the Act. Most states had approved SIPs in effect by 1972.

By 1976 it was evident that many deadlines had already been missed and that others were very likely to be missed. Congress recognized that something had to be done and began an extensive revision of the Act, not only to relieve the deadlines, but also to deal with the many problems and deficiencies that had been identified during the 6 years since the last major revision. The result of almost 2 years worth of lobbying and debate resulted in the 1977 Amendments, which specified significant changes from the Clean Air Act of 1970.

National Ambient Air Quality Standards

To date, EPA has established NAAQS for six pollutants—sulfur dioxide (SO_2), total suspended particulates (TSP), carbon monoxide (CO), nitrogen oxides (NO_x), photochemical oxidants (O_x), and hydrocarbons (HC). Similar standards for lead (Pb) are expected shortly. Under the 1970 Act, all areas of the country were required to attain the NAAQS by July 1975. Many areas of the country (primarily urban) have not yet attained the standards. In view of this, the 1977 Amendments require that each state identify those areas that have not yet complied with the standards and develop strategies that will ensure the attainment and maintenance of the primary standards by December 31, 1982 and the secondary standards as soon as possible. Congress has established strong sanctions for those areas for which SIP revisions are not approved by July 1979, including not permitting new sources to locate in or near the nonattainment area and establishing limitations on Federal highway funding and other Federal funds.

A result of this effort to attain and maintain the NAAQS may be further control of emissions from the forest products industry. Each state and local agency will be taking a much closer look at the sources that may be causing or contributing to the nonattainment problems. This may well result in emissions limitations for sources that were not previously regulated, as well as stricter regulations for sources with existing emission limitations. Sources that are likely to be considered are pulp mills, hogged fuel boilers, saw mills, material handling operations, and prescribed burning.

New Source Review

The Clean Air Act also establishes a New Source Review procedure. This is basically a permit program that allows a new source to be constructed or operated only if it will be in compliance with various requirements of the Act. There are four programs that comprise New Source Review: preconstruction review for compliance with the NAAQS, New Source Performance Standards (NSPS), National Emission Standards for Hazardous Air Pollutants (NESHAPS), and the Prevention of Significant Deterioration (PSD).

The preconstruction review program simply ensures that any new source will not cause or contribute to violations of the NAAQS. This review can be complicated if the area in or near which a source proposes to locate is already exceeding the standards. Congress established two procedures, called the offset policy, to assure that new growth is not prevented but also that clean air is still attained. An offset occurs when emissions from one or more sources are reduced so that the overall air quality is improved, even though a new

source of emissions has located in the area. These emission reductions either can be obtained by the new source proposing to locate, or the SIP can have a formalized schedule for reducing emissions from existing sources to accommodate growth and still attain the NAAQS by 1982. New sources in the nonattainment area also will be required to comply with the lowest achievable emission rate (LAER) by installing the ultimate in control technology.

The NSPS cover emission limitations, equipment, and design standards for specific categories of new stationary sources. EPA has promulgated NSPS for 24 source categories, including hogged fuel boilers capable of firing fossil fuels for backup. Congress also has required that EPA identify and promulgate standards within 4 years for all source categories that contribute significantly to air pollution.

NESHAPS are emission limitations and design, equipment or work practice standards for sources emitting pollutants that are especially hazardous to human health. Currently there are standards for sources of asbestos, mercury, beryllium, and vinyl chloride. Standards for benzene are imminent. These standards apply to both existing and new sources; new sources must obtain a permit prior to construction.

The fourth and final portion of the New Source Review program is PSD, which is likely to be the most restrictive requirement for new sources. The PSD section has two requirements: (1) that any new source install and operate the Best Available Control Technology (BACT) for reducing emissions; and (2) that all sources locating in any given area, together, not degrade air quality more than a specified increment. The increments, shown in Table 1, vary from very little degradation in Class I areas (currently national parks and wildernesses, national memorial parks, and international parks) to the greatest allowable degradation in Class III areas (there are currently no Class III areas). In no case will the air be allowed to degrade beyond the NAAQS. All major stationary sources that can potentially emit over 250 tons (226.796 Mg) per year of any pollutant will need a PSD permit before construction can begin. It should be noted that a source locating in or near a nonattainment area may have to satisfy both the offset and PSD provisions.

There is an increased emphasis on New Source Review, especially the PSD and offsets programs. It is evident that the air quality considerations included in a permit to construct a new source or to modify or expand an existing source have become more stringent. Industrial growth in or near nonattainment areas and near Class I areas will require the best control technologies. There probably will be some impact on the forest products industry, because the resource (the forests), and hence the industrial development, is almost always in the vicinity of Class I areas. Air quality considerations will be an important, if not deciding, factor in future land management decisions.

Table 1. Prevention of Significant Deterioration Area Classifications and Allowable Increases

Pollutant	$\mu g/m^3$ [a]	National Ambient Air Quality Standards	
		Primary	Secondary
Class I [b]			
Particulate matter:			
Annual geometric mean	5	75	60
24-hour maximum	10	260	150
Sulfur Dioxide:			
Annual arithmetic mean	2	80	–
24-hour maximum	5	365	–
3-hour maximum	25	–	1300
Class II			
Particulate matter:			
Annual geometric mean	19	75	60
24-hour maximum	37	260	150
Sulfur Dioxide:			
Annual arithmetic mean	20	80	–
24-hour maximum	91	365	–
3-hour maximum	521	–	1300
Class III [c]			
Particulate matter:			
Annual geometric mean	37	75	60
24-hour maximum	75	260	150
Sulfur Dioxide:			
Annual arithmetic mean	40	80	–
24-hour maximum	182	365	–
3-hour maximum	700	–	1300

[a]Maximum allowable increase in micrograms per cubic meter (but not to exceed NAAQS).

[b]Initially included most national parks, national wilderness areas, national memorial parks, and international parks.

[c]Currently, there are no Class III areas.

NOTE: Presently, there are numerical increments only for total suspended particulates and sulfur dioxide. EPA is, however, required to study and promulgate numerical increments for other criteria pollutants by August 1979.

One portion of the PSD program, the new national visibility goal, could potentially impact the forest products industry, particularly with respect to prescribed burning. Congress has created a national goal to remedy existing and prevent future impairment of visibility in the mandatory Class I areas. The strategy to accomplish this goal will include: (1) any major stationary source that may contribute to impairment of visibility must install the Best Available Retrofit Technology (BART) if it was built between 1962 and 1977; and (2) the states must develop a long-term

strategy to accomplish the national goal. This portion of the Act may have an impact on such sources as pulp mills and hogged fuel boilers, as well as prescribed burning.

Compliance and Enforcement

The 1977 Amendments substantially strengthened the enforcement features of the Act by including procedures for levying civil and criminal penalties of up to $25,000 per day of violation and imprisonment for up to 1 year, or both, for violation of Clean Air Act requirements.

Congress also has established a requirement for levying a penalty against sources that are not complying with applicable emission limitations, compliance schedules, or other requirements of the Act or SIP. The penalty will be equivalent to the cost of installing and operating the necessary control equipment for compliance and will be no less than the economic value which the delay in compliance might have for the owner of the source. In general, there no longer will be any economic justification for not installing control equipment, because the cost for complying will be the same as the penalties levied.

Congress now requires that any Federally owned source or Federal activity must comply with both the substantive and procedural requirements of the state and local agencies, such as the states' Smoke Management Plans. This is a change in the concept of Federal supremacy. It has an immediate impact on the forest products industry. This requirement applies to all activities on Federal lands, such as those managed by the U.S. Forest Service or Bureau of Land Management.

Summary

The Clean Air Act, as amended in August 1977, is a strong vehicle for attaining and maintaining clean air in this nation. The emphasis during the next few years will be on improving those areas not yet attaining standards and maintaining or improving air quality in areas that are cleaner than the national standards. The responsibility for implementing the requirements of the Act rests primarily with the state and local agencies, and the strategies they choose will reflect both Federal requirements as well as local conditions. It appears likely that many of the requirements and strategies will impact the forest products industry. Those programs that may have the greatest potential for impact are the PSD and visibility requirements, because of the close proximity of the national parks and wildernesses to the national forests and other forest lands.

Northwest Forestry Burning

Emissions from Forestry Burning

Until recently, monitoring for emissions from open burning were limited principally to industrial pollutants, as governed by the National Ambient Air Quality Standards. Emission factors were determined by relating the quantity of effluent produced to the weight of fuel burned. Emission factors reported for the major effluents from forest fires are highly variable, since differences in fire behavior produce widely different emission patterns. Emissions are affected by the type and conditions of the material burned. Arrangement of material, fuel loading, and burning technique also have pronounced effects. A single emission factor cannot adequately reflect these variations.

Applying a range of factors whenever possible, as suggested by McMahon and Ryan,[1] yields results that are less misleading than those obtained using single factors. The emission ranges for gases (Table 2) represent the best estimate of expected normal field emissions that can be made from existing data. The range for particulate emissions was obtained from a limited number of field measurements of emissions from burning western logging slash.[2]

Compared with other carbonaceous fuels the sulfur content of forest fuels is low; therefore, sulfur oxide emissions generally are considered negligible. Radke et al.[3] measured the gas in five plumes and detected no significant concentrations of gaseous sulfur.

Table 2. Emission Ranges (Dry Weight Basis)[1,2]

Effluent	Emission Range (lb/ton of fuel)
Carbon dioxide (CO_2)	2000-3500
Water (H_2O)	500-1500
Carbon monoxide (CO)	20-500
Particulates (TSP)	17-67*
Hydrocarbons (HC)	10-40
Nitrogen oxides (NO_x)	2-6

*Best available emission range, revised in a private communication by D. Sandberg, March 1978.

Emissions of trace elements from forestry burning have not been reported. However, Darley and Lerman[4] have made some measurements of smoke from laboratory and field burning of agricultural refuse. Quantitative data relating emission rates of some trace emissions to burning conditions are beginning to be reported.[5]

Total estimated emissions of CO, TSP, HC, and NO_x in Oregon and Washington for forestry burning and other source categories are presented in Table 3. High and low emission factors are presented for forestry burning. Other source categories presented in the table are wildfires, field burning, open burning, and all other sources combined. This table indicates that forestry burning contributes substantially to total particulate emissions in the Pacific Northwest. Forestry burning also may contribute significantly to total HC and CO emissions.

The CO emission factors generally quoted were derived from nondispersive infrared measurements evolved from test fires in the burning tower described by Darley et al.[6] Field measurements of CO in fires, adjacent areas, and smoke plumes by Countryman[7] and Fritschen et al.,[8] showed concentrations rapidly diminishing with distance from the source. Such measurements provide information on CO concentrations near the fire zone, but they do not directly relate the mass of CO to the quantity of fuel consumed.

Hydrocarbon concentrations generally have been determined by flame ionization measurements of total hydrocarbons and nonmethane hydrocarbons. However, Hall[9] indicated that flame ionization includes essentially all volatile organic compounds; the hydrocarbons designation, as applied to wood smoke, is misleading. In emission studies from laboratory burning of logging slash,[10] the fire stage greatly influences the composition of hydrocarbon effluent; simple flame ionization measurements did not reflect changes in the composition of the hydrocarbon emission. An example of the complexity of the volatile organic emissions is included in a report by McMahon and Ryan.[1]

Nitrogen oxide emissions from burning forest fuels have not been studied extensively. The factors quoted in various reviews are mainly from Gerstle and Kemnitz[11] and Boubel et al.[12] Oxidation of atmospheric nitrogen requires temperatures greater than 2700°F

Table 3. Statewide Emissions for Oregon and Washington[a,b]

Source Category/State	Total Suspended Particulates[c]	Nitrogen Oxides	Hydrocarbons	Carbon Monoxide
	Tons Per Year			
Oregon:				
Forestry burnings				
Low estimate	22,530	2,650	13,253	26,507
High estimate	88,795	7,952	53,012	662,653
Wildfires	13,045	3,069	18,417	107,432
Field burning[d]	4,100	480	4,300	24,000
Other open burning	4,320	1,363	5,511	24,365
Other sources	98,614	194,421	276,564	1,084,731
Total nonforestry	115,079	199,333	305,292	1,240,528
Washington:				
Forestry burnings				
Low estimate	29,766	3,502	17,509	35,019
High estimate	117,312	10,506	70,037	875,461
Wildfires	3,961	909	5,451	31,300
Field burning[d]	2,200	200	2,600	13,000
Other open burning	5,464	1,082	9,213	49,088
Other sources	142,636	352,275	368,042	1,699,740
Total nonforestry	154,161	354,466	385,306	1,793,628
Oregon and Washington:				
Forestry burnings				
Low estimate	52,296	6,152	30,762	61,526
High estimate	206,107	18,458	123,049	1,538,114
Wildfires	16,906	3,978	23,868	139,232
Field burning[d]	6,300	680	7,400	37,000
Other open burning	9,784	2,445	14,724	73,453
Other sources	236,250	546,696	644,606	2,784,471
Total nonforestry	269,240	553,799	690,598	3,034,156

[a]Emission figures taken from *National Emissions Report (1975): National Emissions Data Systems (NEDS) of the Aerometric and Emissions Reporting System (AEROS)*, U.S. EPA, April 1977, except as otherwise noted.

[b]Sulfur dioxide emissions are not included, since forestry burning does not emit significant sulfur dioxide.

[c]TSP emissions of this table do not include fugitive dust emission due primarily to agricultural tilling (Oregon estimated at 156,776 tons during 1976).

[d]Field burning estimates are taken from *Source Assessment Agricultural Open Burning*, EPA-600/s-77-107a, July 1977, and correspond to the year 1973.

(1500°C), considerably higher than the temperatures achieved in most prescribed fires. However, some nitrogen oxides are formed in these fires, possibly through involvement of hydrocarbon-free radicals, as indicated by Ay and Sichel.[13] Oxidation of fuel also is possible. In either case, NO_x production should be fuel-dependent, with needles, foliage, and duff producing relatively greater quantities than woody fuels.

The emission of particulate matter from fires has been studied more extensively than the emission of gases. Open burning generates particles with organic content that range in diameter from about 0.002 μm to macroscopic sizes. Generally, only particles with aerodynamic diameters smaller than approximately 10 μm remain airborne long enough to impact on air quality. Larger particles fall out of the atmosphere rapidly and can be detected only within short distances from prescribed fires. Multistage impactors with final filters have been used to fractionate particles from burning forest fuels on the basis of aerodynamic properties. Sandberg and Martin[14] found the distribution of particle sizes shown in Table 4 in smoke from laboratory burning of Douglas fir logging slash.

Emission factors are being updated as laboratory-scale burning facilities are made more representative of field conditions. The burning tower described by Darley et al.,[6] in some cases including the modifications indicated by Darley and Biswell,[15] approximates field conditions better than most laboratory installations. The results obtained in numerous studies by various

Table 4. Particulate Emissions from Logging Slash (Mass Basis)[14]

Aerodynamic Particle Diameter	Average Percent
> 5.0 μ	8
1-5.0 μ	10
0.3-1.0 μ	13
< 0.3 μ	69

investigators using the burning tower have been summarized by Wayne and McQueary.[16]

The reliability of emission factors obtained by extrapolating laboratory results also is being improved through correlation with data obtained from field measurements. However, many more emission measurements from actual prescribed fires will need to be performed before complete emission patterns can be reliably projected from burning prescriptions.

Differences in fire behavior and fuel conditions, between laboratory and field situations, must be taken into account when extrapolating laboratory data to obtain emission factors of field fires. For example, Sandberg[2] measured particulate emissions of 6 to 24 lb/ton (2.99 to 11.9 kg/Mg) in laboratory fires and 28 to 107 lb/ton (13.97 to 53.38 kg/Mg) in field fires where western logging residue was burned. The emission factor of 17 pounds of particulate matter per ton of fuel (8.48 kg/Mg), which has been used by Yamate[17] as the basis for estimating atmospheric emissions from forest fires, is compatible with the laboratory values but well below the range of the field emissions.

Potential Air Quality Impacts

The initial plume characteristics, meteorology, and the terrain affect the transport, dispersion, deposition, and transformation of forestry burning emissions and hence their impact on air quality. Complex terrain airflow and dispersion models can be used to predict the pollutant concentrations that result from large smoke plumes of slash fires. The available literature does not reveal any modeling studies that specifically determine the impact of slash burning activities on the smoke-sensitive regions of the Pacific Northwest. However, the LIRAQ model developed at Lawrence Livermore Laboratories[18] and the complex terrain model by Fosberg[19] are currently undergoing validation in the Willamette Valley region of Oregon by the Oregon Air Resources Center at Oregon State University.

The presence of potentially harmful emissions from forestry burning has been documented. The health and environmental effects of CO and NO_x, which are also industrial pollutants, have been cited in numerous studies. Some hydrocarbon and volatile organic emissions are unique to open burning. Their effects have not been studied as extensively as those of the industrial pollutants.

Ethylene, one of the major hydrocarbon emissions, can injure susceptible plants; however, smoke exposure from prescribed fires is usually too short to cause serious plant damage, except in cases of poor ventilation, when smoke stagnates at ground level in areas adjacent to a fire. Feldstein et al.[20] estimated that the ethylene concentration 1 to 2 miles (1.6 to 3.2 km) downwind from a fire burning 2000 tons (1818 Mg) of landclearing debris was 0.5 to 2 ppm and persisted for approximately 3 hours. Susceptible vegetation in the exposed area could have suffered ethylene damage in this time, though none was reported.

Relatively small quantities of potentially photochemically reactive compounds, such as olefins, diolefins, and substituted aromatics, are released by forest fires. Downwind photochemical formation of ozone and other oxidants from these and nitrogen oxides is dependent on various plume and meteorological parameters. Evans et al.[21] reported increased ozone concentrations in the upper layers of smoke plumes from field fires in Australia. Radke et al.[3] measured above-ambient concentrations of ozone in plumes from burning logging residue in Washington State.

Trace constituents emitted by forest fires have greater potential for producing adverse health effects than the major effluents. The volatile oxygenated organic compounds, such as acids, ketones, alcohols, aldehydes, and furans, produced by fires are partially absorbed/adsorbed by condensing smoke particles. The particle-bound vapors retain activity longer than they would in the gaseous state and can be transported long distances from the fires. Polycyclic Organic Materials (POM) are formed by pyrosynthesis in all inefficient combustion processes. Some of these compounds have been identified as carcinogens and others are potentially carcinogenic.

Available data shows no direct evidence of adverse health impacts from forestry burning in the Pacific Northwest; however, as mentioned earlier, forestry burning has been shown to be a significant source of particulate matter in this region. Particulate emissions from forestry burning also can obscure visibility. Smoke intrusions into urban areas contribute to particulate haze from industrial and transportation sources. Forestry burning also may adversely affect the aesthetic visibility of pristine landscapes. Smoke plumes can elicit negative reactions in rural areas, since smoke and haze are commonly associated with urban air pollution.

Trends in Burning

The need for prescribed burning is expected to decline on a long-term basis.[a] By the year 2020, most old-growth timber will have been harvested, leaving commercial stands in harvest cycles of 60 to 100 years.[b]

[a]State of Oregon, Interim Task Force on Forest Slash Utilization Final Report. December, 1977.

[b]Personal Communication, J. Todd. USDA Forest Service. October, 1977.

These second-growth stands are expected to create less slash than old-growth timber, thereby decreasing the need for slash disposal. On a short-term basis, State, Federal, and private industry sources foresee an increase in slash burning. More burning is expected because of favorable productivity, cost incentives, and improved burning technology and methodology.

Between 1972 and 1977, the number of acres of slash burned in the Pacific Northwest increased both in Washington and Oregon (Figure 1); however, the trend of total tons burned varied. As Oregon increased, Washington decreased and the region as a whole remained constant (Figure 2). The proportional amount of slash burned measured in tons per acre decreased for both Washington and Oregon (Figure 3). These trends are independent of two abnormal data sets. The 1974 data for Oregon used in these figures were incomplete because of a computer malfunction. The 1976 data for both states reflects an unusually high level of burning because of extremely favorable weather conditions.

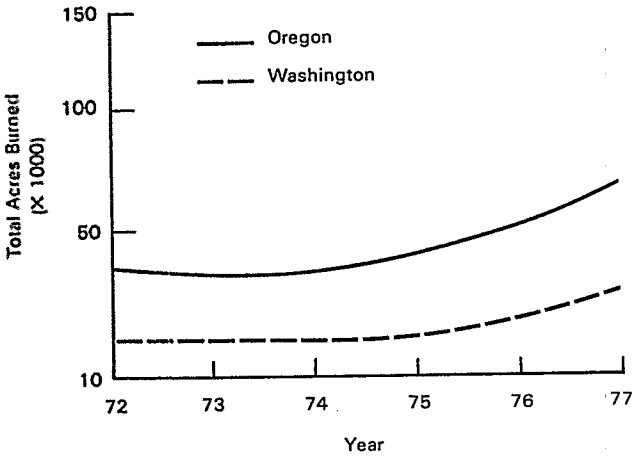

Figure 1. Trend of Acres Slash Burned from 1972-77

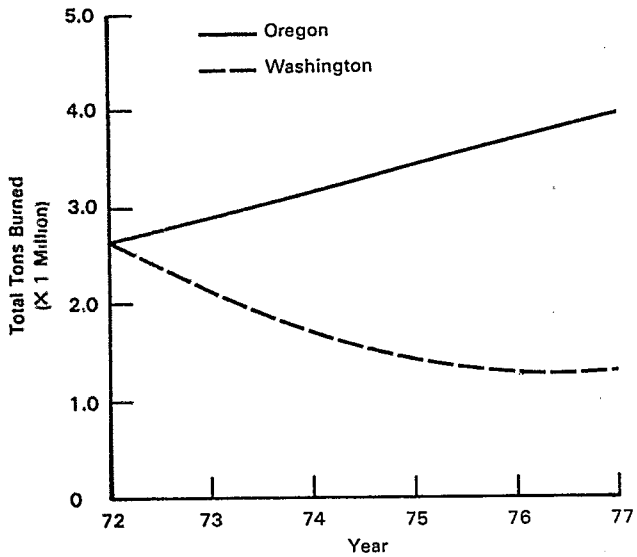

Figure 2. Trend of Tons Burned from 1972-77

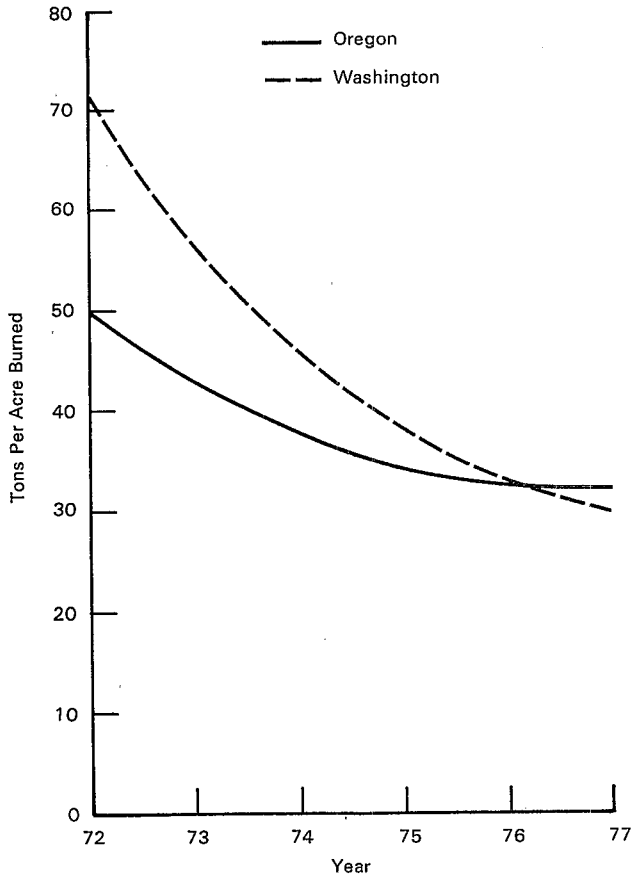

Figure 3. Trend of Tons/Acre Burned from 1972-77

Although there appears to be little change in the total tons of slash being burned in the region, the downward trend of the amount of slash burned per acre may reduce the impact of forestry burning on air quality in the area of the burning.

Conclusion

Forestry burning produces potentially harmful emissions; however, the air quality impacts from forestry burning cannot be accurately predicted due to the lack of definitive ambient air monitoring data in Washington and Oregon. The only active air monitoring installations are located in urban areas where industrial and transportation emission sources contribute to pollutant levels.

In order to arrive at meaningful conclusions regarding the current impact of forestry burning on air quality, it will be necessary to conduct a comprehensive air quality survey to collect data and to provide a basis for definition of specific regions vulnerable to such impacts.

Wood Waste Combustion

Wood waste, once just a nuisance in most forest products industry operations, is now considered a valuable energy resource. As a natural byproduct of the industry's resource utilization, wood waste is an attractive alternative to more expensive fossil fuels. For many years, the industry has used wood-fired boilers to produce process steam and electricity, while at the same time solving a large-scale wood waste disposal problem. In the Pacific Northwest, for example, there are approximately 1000 industrial wood-fired boilers in operation. Junge[22] reports that annual use of wood fuels in Oregon alone is equivalent to more than 19 million barrels (3.02 million m^3) of oil.

The combustion of wood residues in hogged fuel boilers creates a particulate emission composed of fly ash, or the unburned remains of wood or bark fuel, including sand or dirt picked up during the logging operation. If not controlled, this fly ash can result in visible stack emissions. Most states regulate both the particulate emission rate and the visible emissions, or opacity, of stack effluents. Although the regulations vary from state to state, most requirements can be met with air pollution control devices presently available. The particles emitted from hogged fuel boilers are relatively large and thus relatively easy to collect.

Existing Emission Control Devices

There are a number of control devices presently in use that meet various state air pollution control regulations. These include:

- Low-pressure wet scrubbers [2- to 6-in (5.08 to 15.24 cm) H_2O pressure drop]
- Multiclones in series [4- to 6-in (10.16 to 15.24 cm) H_2O presure drop per unit]
- Multiclones in series with a low-pressure wet scrubber
- Variable-throat venturi scrubbers [10- to 15-in (25.4 to 38.1 cm) H_2O pressure drop]
- Fabric filtration (baghouse)
- Multiclones in series with a portion of the exhaust gas separated for wet scrubbing.

Cyclone separators and spray towers are alternate methods of control; however, as air pollution laws are tightened, these inevitably will give way to one of the above methods to comply with regulations.

Low-Pressure Wet Scrubbers

The best installation for low-pressure wet scrubbers is following a primary collector, such as the multiclone. One of the first wet scrubbers of this type was installed at the Hoerner Waldorf Corporation's Missoula, Montana mill. The boiler at this mill is a 1963 Springfield upgraded from 126 million lb/hr (15.86 Mg/s) to 150 million lb/hr (18.88 Mg/s), operating at 600 psig (4.14 MPa) and 750°F (399°C). The boiler was originally equipped with a conventional multiclone collector and emitted fly ash at a rate of 0.74 grains per standard cubic foot (gr/scf) (1.70 g/m^3), corrected to 12 percent CO_2. More stringent regulations required that additional controls be installed. Hoerner Waldorf installed two parallel, Size 56, Type D, Turbulaire stainless steel scrubbers following the multiclones. Designed gas volume was 155 million acfm (73.1 thousand m^3/s) at 490°F (254°C) and 5-inch (12.7 cm) H_2O pressure drop. Performance tests after startup indicated that the emission rate was reduced to 0.016 gr/scf (0.036 g/m^3) or about 16 percent of the maximum allowed. Overall collection efficiency of the system is reported to be 99.5 percent.

Kirby Lumber Corporation installed a similar type scrubber in 1972 at its Silsbee, Texas mill. Primary multiclones were installed originally on 100-million-lb/hr (12.59 Mg/s) boilers emitting particulate matter with mass median particle size diameter of approximately 9 μm and a total emission rate from the multiclones of approximately 250 lb/hr (113.4 kg/hr). The boilers, installed in the early fifties, were equipped for tangential gas firing at a rate of 120 million lb/hr (15.11 Mg/s) and with traveling grates for wood firing at a rate of 100 million lb/hr (12.59 Mg/s). Texas adopted more stringent regulations in January 1972, to become effective December 31, 1973. These regulations required that Kirby's boilers emit no more than approximately 40 lb/hr (18.2 kg/hr) of particulate matter and that the stack have an opacity no greater than 30 percent.

Emission rates for the boilers prior to scrubber installation are shown in Table 5. After installation of carbon steel scrubbers, the emission rate from each stack was 7.4 lb/hr (3.4 kg/h), giving an overall removal

Table 5. Stack Sampling Data (Before Scrubbers) Kirby Lumber Corporation

	Stack 1	Stack 2
Flue Gas Rate (acfm)	72,400	62,800
Flue Gas Rate (scfm)	45,000	41,100
Emission Rate (lb/hr)	263	192
Dry Bulb Temp. Flue Gas (°F)	401	350
Wet Bulb Temp. Flue Gas (°F)	145	136

efficiency of 97 percent. The regulation limit for each stack was 41 and 33 lb/hr (18.6 and 15.0 kg/hr); thus, Kirby was able to reduce the emission rate from each scrubber to approximately 18 percent of that allowed by regulations. The cost of the 2-boiler scrubber installation was $50,000 in 1972.

Since these initial scrubber installations, a number of scrubbers have been installed. In 1974, an Alabama plywood plant installed a 110,000-lb/hr (13.8 kg/s) hogged fuel boiler, whose scrubber is preceded by a mechanical collector. Temple Industries has two such installations: one at Diboll, Texas and the other at Pineland, Texas. Both include single multiclone collectors followed by a wet scrubber.

Multiclones (Two in Series)

Theoretically, it should not be advantageous to install a multiclone in series with the same size tubes and with the same pressure drop, since each particle of a given hydrodynamic diameter has a specific collection efficiency. In practice, however, the mechanical action in the cyclones contributes to a certain amount of size reduction and subsequent re-entrainment. For example, a particle of a given size might be collected with an efficiency of 85 percent, but may break up into smaller particles that have individual efficiencies of, for example, 50 percent. To overcome this problem, two multiclones have been installed in series and have proven quite effective in meeting state regulations.

Kirby Lumber installed two multiclones in series on a small boiler, reducing particulate emissions to 24 percent of that allowed by Texas regulations. At a Bon Wier, Texas installation, a 120,000-lb/hr (15.1 kg/s) boiler uses multiclones in series.

Although dry collectors offer less operating problems than wet scrubbers, caution must be exercised in selecting the proper system. Dirty, wet fuel could present problems in achieving rated efficiency. Wet scrubbing has a slightly higher collection efficiency, but presents problems with sludge disposal, as well as corrosion if coal firing is contemplated.

If series multiclones will not meet regulations, their operation may be improved by treating a portion of the total gas stream (i.e., approximately 20 percent of the stack gas), scrubbing, and then returning the clean gas to the stack. Additional Induced-Draft (ID) fan capacity must be provided for this operation.

Venturi Scrubbers

Venturi scrubbers have been used on hogged fuel boilers in the 150-million-lb/hr (18.85 Mg/s) range. A single multiclone was replaced with a parallel, variable-throat venturi scrubber. Multiclone emissions averaged 0.597 gr/scf (1.37 g/m^3) [276 lb/hr (125 kg/hr)]. Average scrubber discharge is 78,500 acfm (37.04 m^3/s), containing 0.0035 gr/scf (0.008 g/m^3) [1.74 lb/hr (0.79 kg/hr)], which represents a 99.9+ percent collection efficiency. Pressure drop is reported to be approximately 10 in (25.4 cm) H_2O through the venturi and 20 in (50.8 cm) H_2O through the entire control system. Cost of this system is estimated at $4.50 per scf, as compared to $1.16 per scf for the low-pressure type.

Fabric Filtration (Baghouse)

Bark boiler emissions at Simpson Timber Company's Sheldon, Washington mill are controlled by the use of a baghouse. This application was utilized to control the high sodium chloride content and objectionable opacity of the plume caused by burning logs saturated with salt water. Although the initial and operating costs of fabric filtration are quite high, its principal advantage over wet scrubbers is the ability to handle and dispose of collected dust. A recent quote for a baghouse installation on a 100,000-lb/hr (12.59 kg/s) boiler was approximately $200,000.

Dry Scrubber

A dry scrubber has been operating for about 4 years at Weyerhaeuser's lumber mill in Snoqualmie Falls, Washington. The gas flow rate is 55 million acfm (26-thousand m^3/s) at 350°F (176°C) and a pressure drop of approximately 5 in (12.7 cm) H_2O. The average emission rate from this dry scrubber is 0.05 gr/dscf (0.115 g/m^3).

The dry scrubber consists of a cylindrical vessel containing two concentric, louvered, cylindrical tubes. The annular space between the tubes is filled with pea-sized gravel. Particulate-laden gas enters the filter through appropriate ducting and is distributed to the filter face by the plenum section formed between the outlet louvered cylinder and the vessel wall. Dirty gases pass through the filter at velocities ranging from 100 to 250 fpm (0.508 to 1.27 m/s). The gravel media is continuously changed by a downward flow carrying the gravel and particulate matter into a shaking mechanism that separates the particulate from the gravel. The gravel media is returned to the top.

Summary

Particulate emissions from hogged fuel boilers can be controlled with relatively low-cost equipment, such as series multiclones or a multiclone in series with a low-pressure-drop wet scrubber. Other devices, such as venturi scrubbers, fabric filters, and dry scrubbers,

are considerably more expensive but may fill special needs. In selecting a method of control, each case must be evaluated with consideration given to:

- Cleanliness and moisture content of fuel
- Proximity to highly populated area
- Particle residence time in furnace
- Availability of solid waste disposal area
- Governmental regulations.

Particulate emissions from hogged fuel boilers can be reduced through proper fuel characteristics and careful combustion control. Research in these areas has been conducted recently at Oregon State University, as described in the following paragraph.

Fuel and Combustion Research

Introduction

Present technology affecting the design and operation of wood-fired boilers is limited. As a result, a large percentage of both new and older facilities are experiencing difficulty in operating efficiently and in meeting environmental restrictions.

The technology gap focuses about the rate of combustion of the fuel and factors that affect combustion rates. For example, it is known that moisture influences combustion (dry fuels burn faster than wet fuel), but there is little data for predicting the specific influence of moisture. Similarly, the size of the fuel can be expected to have a significant effect on the combustion process (small size will burn more rapidly than large size), but there are no comparative numbers to indicate how important size is in completing the combustion reaction. This makes it difficult to respond to such often asked questions as, How small should wood fuel be before it goes to the boiler? and, How dry should it be for good combustion to occur?

Another important question that engineers, designers, and operators ask is, How much fuel can be fed to the boiler and still keep within the emission standards? This problem is usually approached by rule-of-thumb estimates, such as, the maximum fuel flow rate should result in 1,000,000 Btu/hr/ft^2 (3150 kW/m^2) of grate area. Such rules of thumb do not take into account the variations in fuel size, moisture, inlet air temperatures, species of wood, ratios of overfire to underfire air, etc. These parameters are not considered because the data is not available in the literature.

Recognizing that there are many unanswered questions regarding the combustion of wood fuels, Oregon State University obtained funding from the Energy Research and Development Administration (ERDA), Division of Conservation Research and Technology in April 1976, (reorganized into the Department of Energy in 1977) to study combustion of wood residue fuels and the factors that influence combustion.

Design of the Experiments

The overall experimental program was to study the influence of normal industrial process combustion variables on the combustion of wood residue fuels. These variables were to include fuel species, fuel size, fuel moisture, percent of excess air, and percent of undergrate (underfire air) and overfire air.

To study the effects of these variables, the amount of unburned carbon and noncombustible ash carried out of the combustion chamber per unit of time was determined for each firing condition. This parameter was used as a measure of the completeness of the combustion reaction in the test facility. High levels of combustible carbon carryover indicate poor combustion conditions; low levels of carryover indicate better combustion conditions.

Carryover was determined gravimetrically by weighing the material collected by the cyclone separator. The rate of carryover was expressed in pounds per hour [lb/hr (0.126 g/s)]. The amount of unburned carbon in the total carryover was determined by laboratory analyses.

Data was collected for 79 combustion test conditions using Douglas fir bark. Replicate experimental runs were made for 29 of the 79 test conditions. The overall experimental program is displayed graphically in Table 6.

Data Collected

For each test run, data was collected for independent and dependent variables. The independent variables included fuel-related species; size range; moisture content; density; feed rate; temperatures at forced draft fan exit, undergrate air duct, front overfire air duct, rear overfire air duct, and bypass air duct; gas (air) flow rates at forced draft fan exit, front overfire air duct, rear overfire air duct, bypass air duct, and fuel conveyor air cooling duct; and weather conditions.

The dependent variables on which data was collected for each test run included combustion zone temperature 18 in (45.72 cm) and 60 in (152.4 cm) above the grate, at the inlet to the air preheater and at the exit from the air preheater; ash carryover rate from the discharge of the cyclone; percent excess air as determined by oxygen analyses; and opacity from the gas discharge of the cyclone.

Results of the Experiments

The highlights of the experiments are presented in Table 6 to show the impact of variations within the parameters of fuel size, fuel moisture level, fuel feed rate, and amounts of overfire and underfire air. Shown is the rate of carryover of ash (including both combustible and inorganic ash) as a function of levels of excess air. Increasing levels of carryover indicate decreasing levels of combustion efficiency. Low levels of carryover indicate more complete combustion of the wood residue fuels.

Table 6. Graphic Display of the Design of the Experimental Program

		Test Numbers in the Test Series Indicated[c]															
		1-3	4-7	8	10-12	13-17 & 33-39[a]	27-29	18-21	25-26 & 30-32	22-24	46-52	40-45	53-57[a]	58-62[a]	63 & 64-69[a]	70-75[a]	76-79[b]
Fuel Size	Fines (X_1 ¼ inch)					✓	✓	✓	✓	✓	✓	✓					
	Large (⅜ inch-¾ inch)												✓	✓	✓	✓	✓
	Std. Mixed Hogged Fuel	✓	✓	✓	✓												
Fuel Moisture	Wet (53%-56%)	✓	✓	✓	✓						✓	✓			✓	✓	✓
	Dry (38%-42%)					✓	✓	✓	✓	✓			✓	✓			
Fuel Feed Rate	Low (363 Dry lb/hr)	✓															
	Med (567-689 Dry lb/hr)		✓		✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓
	High (836-850 Dry lb/hr)			✓					✓	✓							
Inlet Air Distr.	Max. Undergrate Air (90%-98%)	✓	✓	✓		✓	✓		✓		✓			✓		✓	
	Max. Overfire Air (90%-95%)				✓			✓		✓		✓	✓		✓		
Inlet Air Temp.	Low (70°F)						✓										
	Med (250-300°F)	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

[a]Indicates that the tests in the series were replicated once.

[b]Tests 76 through 79 used varied amounts of overfire and underfire air @ 50% excess air.

[c]The tests in each series shown held the indicated variables constant and varied levels of excess air (i.e., the test series 1-3 involved 3 levels of excess air).

The levels of excess air are measured downstream from the combustion zone and are indicated on a percentage basis. Thus, 0 percent would indicate that stochiometric combustion conditions existed in the combustion zone. A 50-percent level of excess air indicates that 50 percent more air was supplied to the combustion zone than was needed to complete the combustion of the fuel for the conditions stated. For each element presented in the graphs, an interpretation of the data is provided in the following paragraphs to aid in understanding the results of the experimental data.

Fuel Size

Figure 4 illustrates a comparison made between the combustion characteristics of large dry wood fuel and small [¼ in (0.63 cm) or less] dry wood fuel. The combustion regime is limited undergrate air, comparable fuel feed rates, and inlet air temperatures. This figure indicates that the effect of fuel size under these combustion conditions is negligible. Based on related data, the critical parameter under these test conditions is the utilization of high levels of overfire air and limited undergrate air. It also should be noted that increasing levels of excess air have limited effect on the completion of the combustion reaction.

As shown in Figure 5, fuel size also appears to be

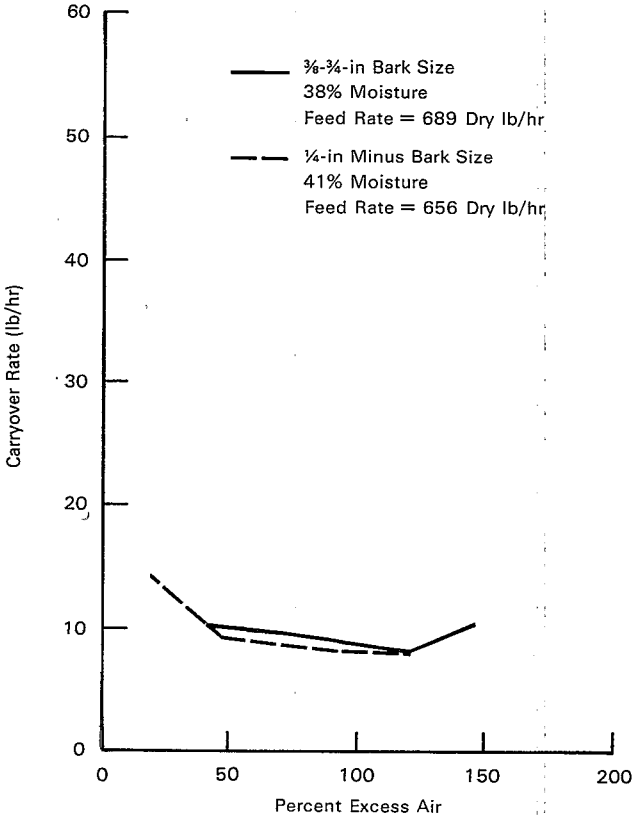

Figure 4. Comparison of the Ash Carryover Rates in Combustion of Dry Bark Fines vs. Dry Bark Coarse Fuel: Maximum Overfire Air

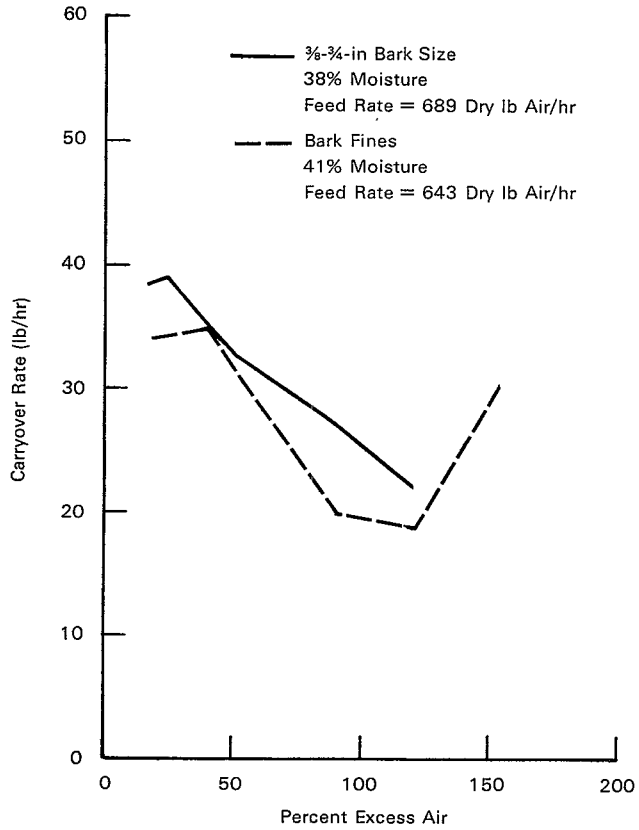

Figure 5. Comparison of the Ash Carryover Rates in Combustion of Dry Bark Fines vs. Dry Bark Coarse Fuel: Maximum Underfire Air

of little impact when undergrate air levels are increased. With high levels of undergrate air, comparable fuel feed rates, and comparable inlet air temperatures, the effect of fuel size is relatively small, perhaps even negligible. The influence of excess air under these combustion conditions is pronounced, with the most complete combustion taking place in the range of 75- to 125-percent excess air.

Moisture Content

Figure 6 illustrates a comparison made between the combustion characteristics of wet versus dry fines utilizing undergrate air as the primary combustion air source. The fuel feed rates and inlet air temperatures are comparable.

This mode of combustion shows a combined influence of undergrate air and fuel moisture levels. The dry (41 percent moisture) fuel appears to increase in combustion efficiency as the levels of excess air are increased. Wet (56 percent moisture) fines decrease in combustion efficiency with increased levels of excess air. The difference in response undoubtedly reflects the longer residence time requirement for the wet fuels to go through the combustion process. From this it can be concluded that moisture levels in fuel principally affect the smaller size fractions of the fuel. This

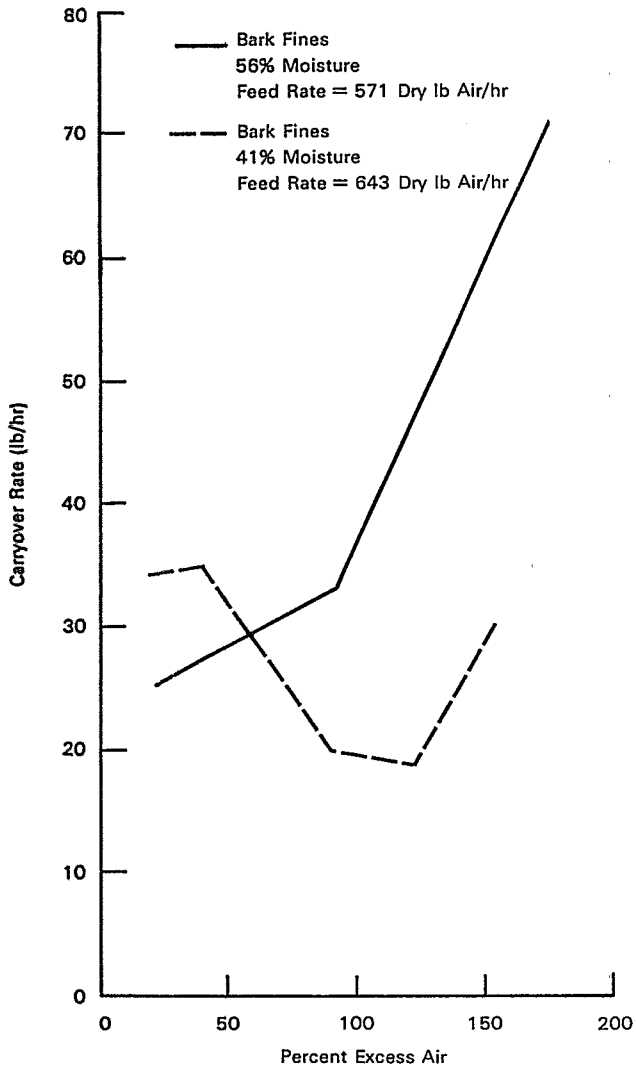

Figure 6. Comparison of the Ash Carryover Rates in Combustion of Dry Bark Fines vs. Wet Bark Fines: Maximum Underfire Air

effect is very pronounced under conditions of high levels of undergrate air.

Amounts of Overfire and Underfire Air

Several test runs compared the use of primarily undergrate air versus primarily overfire air. Carryover rates under these two modes are shown in Figure 7 for dry (41 percent moisture) small-sized fuel particles. As can be seen, the location of the incoming combustion air has a strong influence on the combustion reaction. The effect is particularly pronounced under these specific fuel feed rates and combustion conditions.

Using larger-sized fuel particles, operating in the same modes, carryover rates were again shown to be lower for the maximum overfire air mode. As illustrated in Figure 8, low levels of undergrate air result in

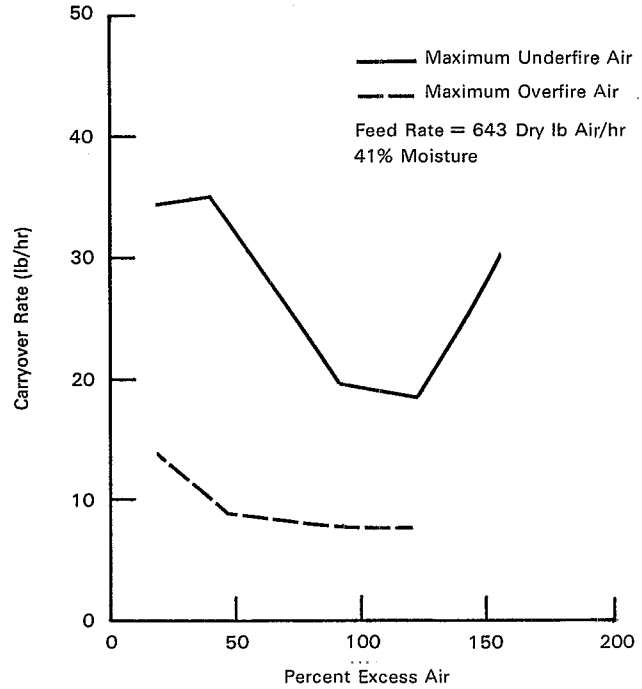

Figure 7. Comparison of the Ash Carryover Rates in Combustion of Dry Bark Fines Using Maximum Underfire and Maximum Overfire Air

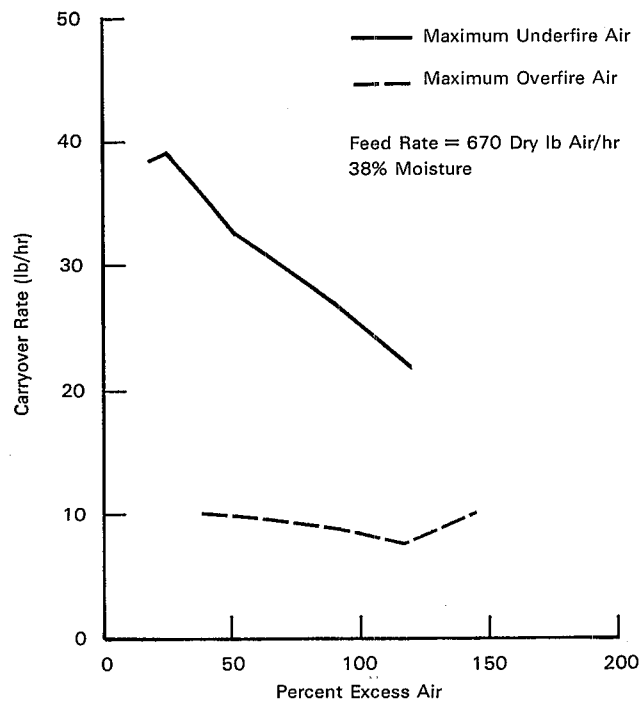

Figure 8. Comparison of the Ash Carryover Rates in Combustion of Dry Coarse Bark Using Maximum Underfire and Maximum Overfire Air

better combustion of the dry bark fuel. In this case the carryover at 50-percent excess air for overfire air is roughly one fourth the carryover rate for undergrate air.

Exhaust Gas Opacity

For most (but not all) of the experimental test conditions, opacity of the exhaust gas from the cyclone was measured by eye. The results are summarized on Figures 9 and 10. Figure 9 is a plot of exhaust gas opacity versus percent excess air for all of the tests in which high levels of overfire air were used in conjunction with low levels of underfire air. The data shown represents all fuel sizes, moisture levels, etc. Only one data point exceeded 20-percent opacity.

By contrast, Figure 10 is a plot of exhaust gas opacity versus percent excess air for those tests in which low levels of overfire air were used in conjunction with high levels of underfire air (typical of firing practices in most spreader-stoker boilers). In this case the opacity levels exceeded 20-percent opacity in 34 percent of the tests conducted. Seven of the tests had opacity levels approaching 40-percent opacity, and two tests had opacities reaching 80 percent.

Opacity is a commonly used measure of pollutant emissions from woodfire boilers (as well as other sources of pollutants). Because of the emphasis by regulatory agencies on this parameter, these results are indeed important and serve to emphasize the benefits of firing boilers with proper locations for combustion air input.

Summary of Significant Research Results

Research on the combustion characteristics of wood residue fuels was performed in a water-wall-cooled, spreader-stoker combustion test facility equipped with a fixed pin-hole grate. Douglas fir bark was used exclusively, but with varied fuel size, fuel-moisture content, fuel-feed rates, levels of excess air, and location of inlet combustion air. Results of the experiments are summarized as follows:

- There is a significant interaction effect on combustion efficiency between fuel size, fuel moisture content, levels of excess air, and location of the inlet air for combustion.
- The effect of fuel size on combustion efficiency is limited. Test data indicates that fuel size fractions less than ¼ in have generally lower emissions of unburned solid carbon than larger size fractions.
- Fuel moisture effects are minimal on combustion efficiency for some modes of operation, but may be highly significant for small size fractions coupled principally with undergrate air feed. The effects of moisture are negligible when the undergrate air flow is limited to low levels and the majority of the combustion air flow is provided as overfire air.
- The carryover of unburned carbon from the combustion zone is roughly linearly related to fuel feed rates (heat release rates) when air is supplied as undergrate air. For normal operation of spreader-stoker combustion systems, one can expect carryover

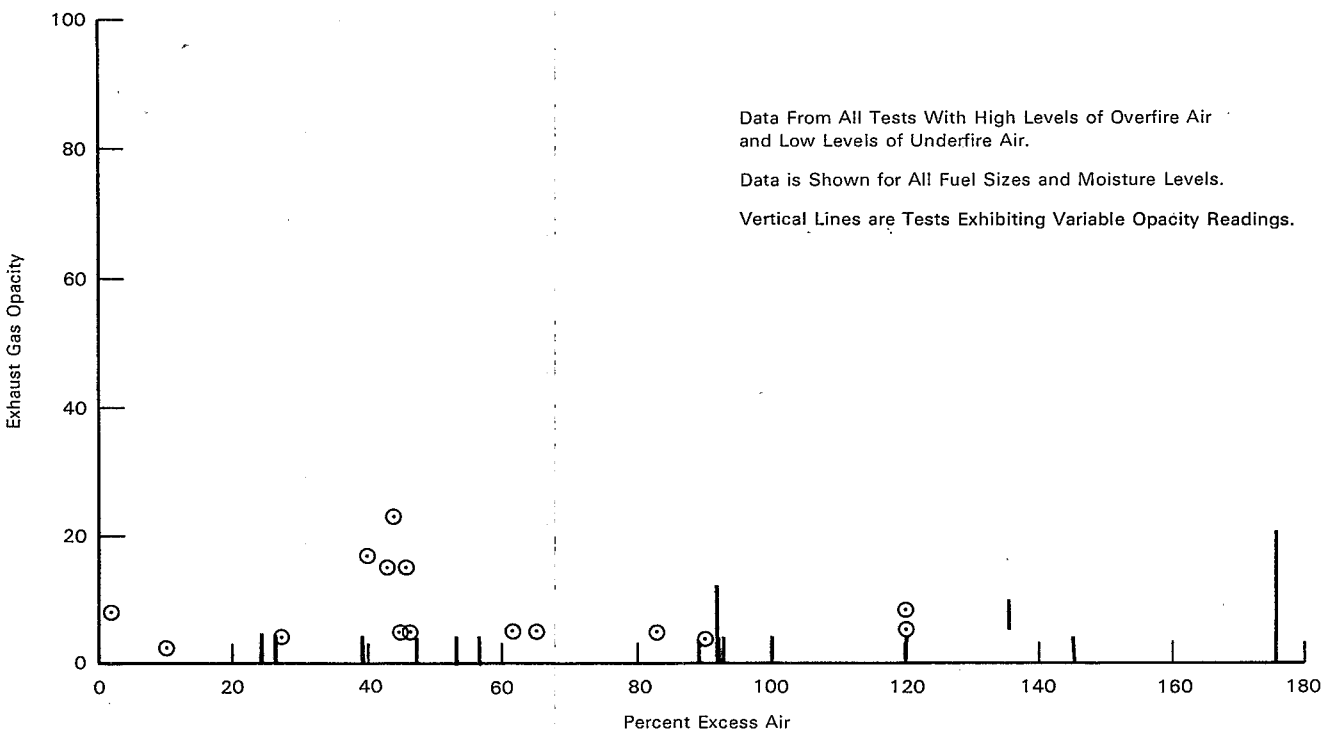

Figure 9. Plot of Exhaust Gas Opacity Versus Percent Excess Air

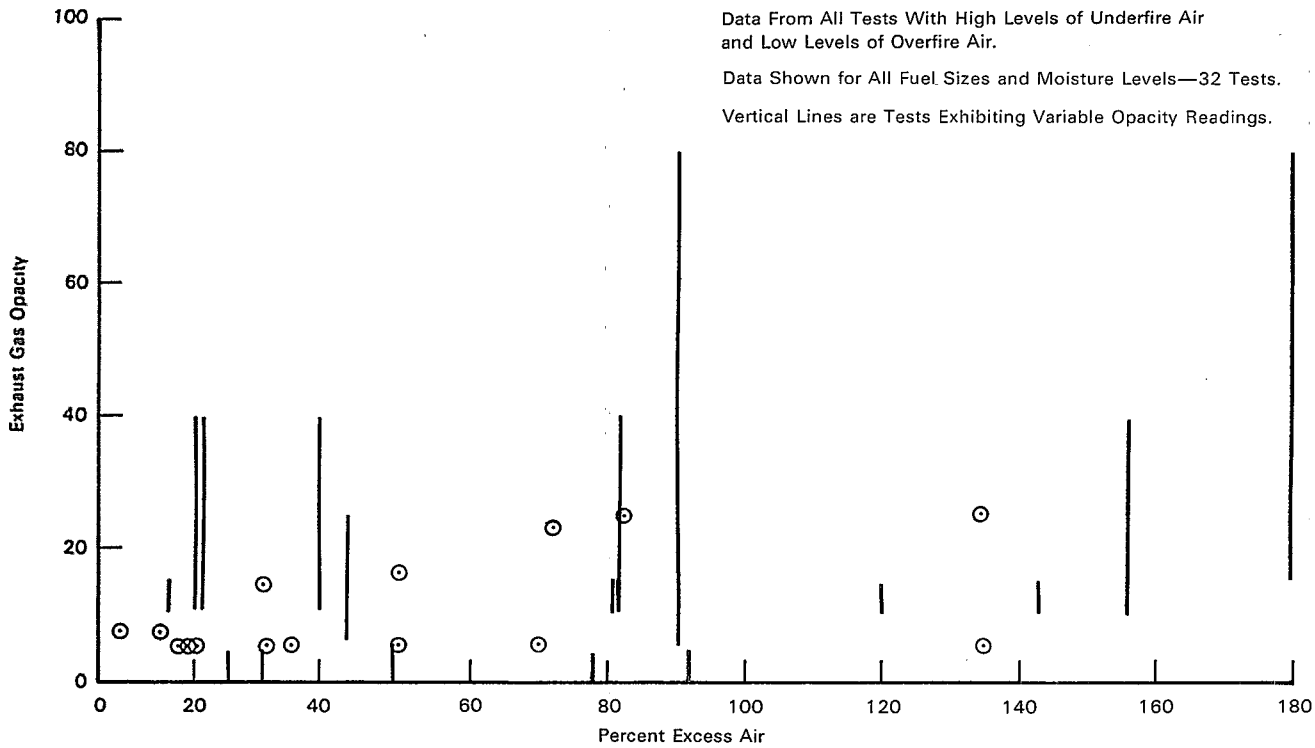

Figure 10. Plot of Exhaust Gas Opacity Versus Percent Excess Air

concentrations from the combustion zone of 3 gr/scf (6.9 g/m^3) at heat release rates of 0.52 million Btu/ft^2 (5905 MJ/m^2) of grate area. The concentration may approach 5 gr/scf (11.43/m^3) at heat release rates of 0.72 million Btu/ft^2 (8177 MJ/m^2) of grate area.

- Wood fuels are roughly 80-percent volatile on a dry basis. It is predicted in theory and now shown in practice that combustion efficiency and stack gas opacity can be improved by taking advantage of this characteristic of the fuel by burning it in two-stage combustion; that is, by strictly limiting the flow of undergrate air to levels approaching 10 percent of the total air flow and making up the remainder of the combustion air by overfire air. Thus, the solid carbon portion of the fuel is allowed to burn to CO on the grate with very low vertical gas velocities. The volatile portion of the fuel is burned above the grate at the level of the overfire air inlet ports. This mode of operation permits combustion at relatively low levels of excess air. This finding is perhaps the most significant of the research effort to date.

Veneer Dryer Emissions

At the point of discharge from the exhaust stack, veneer dryer emissions consist of hot air, a small amount of wood fiber, water vapor, and gaseous organic compounds that have been distilled from the wood veneer. The character and quantity of these steam-distilled organics are related to the wood species, the drying temperature, the humidity in the dryer, and the type of dryer.

In the early 1970's, state and regional air pollution control agencies formed a committee to establish a source test procedure for determination of particulate emissions from veneer dryers. This test procedure addressed only the distilled organic gases that condensed at standard temperature [70°F (22°C)]; these were classified as particulates. Subsequent tests on local veneer dryers demonstrated that, for the most part, veneer dryers met current emission standards for existing sources. Control of dryer emissions was subsequently directed toward reducing the visible blue-haze emissions to 10- to 20-percent capacity. The noncondensible fraction of these organic emissions was not addressed until recent studies showed that photochemical oxidants were exceeding air quality alert levels in many parts of the country.

Photochemical oxidants are formed by chemical reactions in the atmosphere between reactive hydrocarbons and oxides of nitrogen in the presence of sunlight. EPA's strategy for achieving air quality standards for photochemical oxidants is to reduce emissions of hydrocarbon precursors. According to the EPA strategy, reducing hydrocarbon emissions from industry sources and motor vehicles would limit the amount of hydrocarbons available for sunlight-induced reaction and thus reduce photochemical oxidants.

A closer look at what is being emitted from a veneer dryer stack reveals that initially direct condensation of the less-volatile organic gases occurs, producing particles that make themselves evident as a visible blue-haze plume (Figure 11). These condensible hydrocarbon emissions are unique to wood products and are produced almost exclusively by veneer dryers. The condensible organics average about 70 percent of the total organic emissions from veneer dryers. The lifetime of these primary particles is short; in the absence of chemical reactions, a major portion of the condensed organics quickly revaporizes. The fate of those veneer dryer emissions, which remain permanently in particle form, can be predicted, if the particle size distributions and the chemical reactivity of the particles is known. If the chemical reactivity is low, these particles can be treated as any other stable group of particles with a similar size distribution. Thus, their lifetime in the local atmosphere can be estimated and models can be used to determine their impact on Total Suspended Particulate (TSP).

The volatile component and the revaporized primary particles have two possible fates. Some of them may

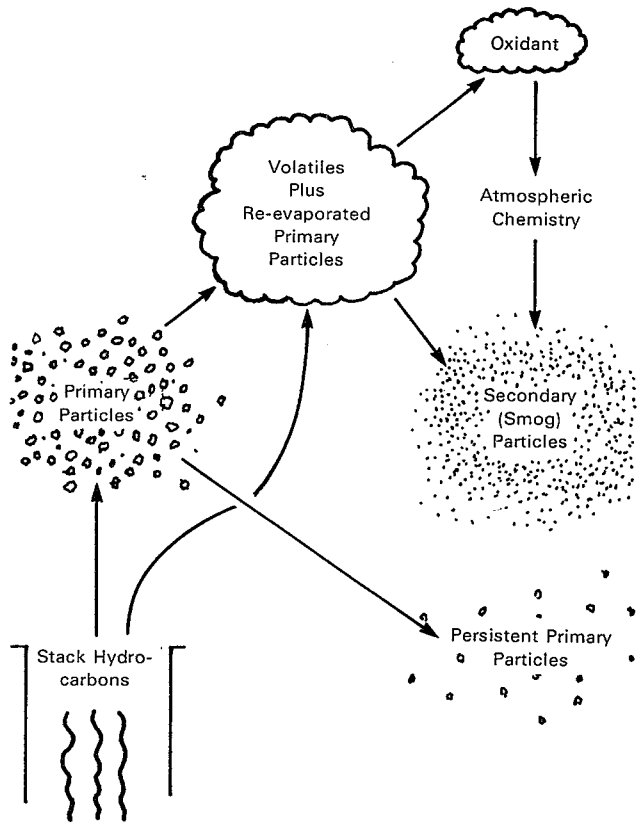

Figure 11. Transport Phenomena of Air Emissions from Veneer Dryers

follow the hydrocarbon-to-oxidant pathway, possibly increasing the oxidant concentration in the area; the rest may follow the hydrocarbon-to-particle pathway, producing secondary particles. These secondary particles are quite distinct from the primary particles evident in the veneer dryer plumes. They are produced slowly, over a period of hours to days and over an entire airshed. They become visible and are associated with the characteristic aerosol haze in rural areas, such as the Smokey Mountains in North Carolina or the Blue Ridge Mountains of Virginia. They also can contribute to urban smog.

Of the possible fates, Washington State University researchers Dr. Dagmar Cronn and Dr. Malcolm Campbell[23] believe that the majority of veneer dryer emissions take the route to particle formation. Campbell, working with related hydrocarbons, observed that more than 80 percent of the hydrocarbons were rapidly converted to secondary particles, leaving less than 20 percent available for oxidant production. Similar conclusions have been reached by Gay and Arnts, researchers with the Environmental Protection Agency, Environmental Sciences Research Laboratory, Research Triangle Park, North Carolina.[24]

On the other hand, in a statement published in the *Federal Register*[25] on July 8, 1977, EPA stated that in the analysis of available data, very few volatile organic compounds are of such low photochemical reactivity that they can be ignored in oxidant control programs. Reactivity scales are measures of the rate at which hydrocarbon compounds react in the ambient air. EPA has classified terpenoids as highly reactive. The classification specifically assumes that all of the hydrocarbon is consumed in producing ozone. There is evidence that this is not true for wood-related hydrocarbons, which actually consume oxidants by reacting directly with ozone in the atmosphere. In fact, Gay and Arnts were able to account for only a small percentage of the heavy, wood-related hydrocarbons that they reacted with nitrogen oxides; the bulk of the hydrocarbons was apparently being converted into particles.

At the request of the American Plywood Association, the team at Washington State University submitted a research proposal with the following goals and objectives:

Project A: Physically and chemically characterize the gaseous and particulate emissions from four or five veneer dryers of varying types and/or feedstocks.

Project B: Determine the lifetime of the primary particle plume above veneer dryers and the fraction of it that is persistent.

Project C: Determine the yields of particles and oxidants from a typical veneer dryer, during a 2-day period of residence of the emissions in the atmosphere.

In their summary, they felt the following data was needed to determine the significance of wood product hydrocarbon emissions in local air pollution.

- Information is needed on the chemical breakdown of hydrocarbons between particulate and gas phases at the stack, using veneer dryers as a source. Older studies of this subject, with categorizations into condensible and non-condensible fractions, are probably misleading. The size distribution and chemical stability of the persistent primary particles need to be determined.
- The ratio of gaseous hydrocarbons going respectively to oxidant formation and secondary particle formation is urgently needed. It is expected that almost all wood product hydrocarbon gases will end up as secondary particles.

Direct-Fired Drying

Tremendous amounts of energy are required to extract water from wood products to make them suitable for use as building materials. Drying is one of the most energy-intensive processes in the forest products industry. This fact, coupled with rising fuel costs, has led many mills to turn toward direct-fuel drying as a more efficient means of heat utilization. With direct-fired drying, the off-gases of combustion are applied directly to the drying process, without using a secondary heat transfer medium.

There are more than 100 direct-fired drying systems in operation, most using wood waste fuel but having provisions for auxiliary fossil-fuel backup. Typical systems have been adapted to lumber dry kilns, plywood veneer dryers, rotary dryers, and flash tube dryers.

It is possible to understand direct-fired dryer systems better through an analysis of system similarities. For a majority, the following apply.

- Some form of fuel preparation is required.
- A portion of dryer emissions is recirculated.
- Dryer emission hydrocarbons and wood particles are destroyed in the recirculation process.
- At least the equivalent of combustion air requirements plus moisture vapor picked up in the drying process is exhausted to the atmosphere.
- A combined effluent of dryer emissions and burner or combustion emissions is exhausted.
- Less heat energy input than for other systems is required to accomplish the same drying production rates.

With direct-fired drying, the process equipment in effect serves as the particulate collector for the products of combustion. It is essential, therefore, that the combustible element of the fuel be consumed completely in burning and that the fuel contain a minimum of noncombustibles which would result in particulate emissions.

The ideal fuel for such direct heating systems should be dry, clean, and sized to permit rapid and complete combustion prior to entering the drying process. A typical direct-fired system for a lumber dry kiln, veneer dryer, or rotary dryer would use a clean, dry fuel, such as planer mill shavings, sanderdust, plywood trim, particleboard trim, or dried sawdust. Typical direct-fired systems require that the fuel be reduced to ⅛ in (0.32 cm) and finer and that the moisture content be less than 20 percent. The small-sized fuel particles and the low moisture content ensure that the process of combustion completely consumes the fuel particles and that only the noncombustible element in the fuel is introduced into the process.

As the products of combustion are passed through the drying process, a large percentage of the dry ash remains on the surface of the material being processed in the dryer. In the case of high-temperature pine lumber kilns on a 24-hour schedule, there is a fine gray residue that remains on the surface of the wood. This residue is completely removed in the planer mill operation and does not result in any degree of pollution. On veneer dryers, because of the relatively short time the veneer is exposed to the heat process, there is no noticeable buildup of ash on the surface. With systems installed on rotary dryers for particleboard, there has been no noticeable color change in the particleboard as a result of being direct-fired with wood residue.

One of the immediate and obvious advantages of direct firing is the resultant efficiency of the heat generated, since there is no loss of heat from steam conversion nor is stack heat lost to the atmosphere. Direct firing on some processes also adds some intangible pollution benefits, particularly in the case of rotary dryers and veneer dryers. A typical veneer dryer, direct-wood, waste heating system involves recirculating kiln atmosphere back through a heating chamber, where the products of combustion from the burner are introduced and mixed with the recirculated atmosphere into a chamber controlled at 1100°F (590°C). This temperature, plus the presence of flame from the burner, helps reduce the amount of blue-haze emission normally associated with direct-fired softwood veneer dryers. The same is true on rotary dryers, where a percentage of the stack emissions can be recycled through the heating system.

With direct-fired drying systems, the fuel required for the burner system must be processed, handled, and stored. In a typical system, the dry-wood residue is introduced into a live bottom surge bin that feeds a controlled amount of fuel to a hammermill. The final hammermill should have a screen with approximately

⅛-in (0.32 cm) openings. In grinding planer shavings, ply-trim, or particleboard trim the resultant grinding produces a fuel that to a large extent is finer than No. 6 mesh; only 25 percent is finer than No. 40 mesh and only a small percentage will pass No. 100 mesh. This fuel size can be successfully collected in a high-efficiency, long-cone cyclone without the need for secondary filters. However, with sanderdust as fuel, normally it is necessary to use the cyclone on the storage bin as a primary collector, and a bag-type filter as secondary collector to meet existing pollution requirements.

A typical system includes a low-pressure blower system from the hammermill to a high-efficiency cyclone on top of the storage bin. The fuel is fed into the burner in a high-pressure system. The burner becomes the collector at the end of the high-pressure system.

Existing systems for direct firing have used dry, clean residues; the rough bark and other wet residues have been left to steam generation. This probably will continue to be the trend in most instances, since a dry, clean, direct-fired wood residue system is by far the simplest and least expensive installation for producing heat from wood residue.

Systems are being developed that can use green fuels and convert the resultant heat energy into clean hot air for the drying process. Some of these systems process green fuel through dryers, producing pellets from the dry bark and using these pellets for boiler feed systems similar to those now being used for burning clean, dry waste. Other systems are being developed that will use unprocessed green hogged fuel to generate direct-fired heat for the heating process.

A recent installation in a lumber mill in east Texas uses an underfeed stoker system to burn hogged fuel on a grate. A regenerative fly ash collector unit is installed in the discharge stream from the furnace chamber to remove all but the finest particulate matter in the combustion gases. This allows the combustion gases to be mixed with recirculated kiln atmosphere and to be introduced into the dry kiln to provide the necessary heat.

Another interesting development is the burner gasifier unit. In this system the green hogged fuel is fed into the burning chamber through an underfeed pipe. Pile burning occurs on a pinhole grate and the underfire and overfire air in the burning chamber are controlled to approximately 1200°F (648.8°C). The volatiles are introduced into a secondary cyclonic burning chamber, where additional combustion air is introduced and rapidly mixed. The secondary burning increases discharge temperatures to approximately 2200°F (1204°C). Emission tests indicate that the discharge gases on green hogged fuel at 60-percent moisture (wet basis) result in 0.156 gr/scf (0.358 g/m^3) of exhaust gas corrected to 12 percent CO_2. If the hogged fuel in the unit is only 35-percent moisture (wet basis), the resultant grain is 0.053 gr/scf (0.12 g/m^3) corrected to 12-percent CO_2. This particular unit is under development, both for direct-firing processes and for introducing the hot gases into existing boiler systems where stack emission problems are particularly critical.

Where new equipment is being added to a mill, or where expensive pollution-control equipment must be added to bring older boilers into compliance, direct firing of appropriate equipment should be considered. In many instances, relieving some steam requirements from boilers can reduce considerably the pollution equipment required. It is also possible that future technology may indicate that alternative ways of burning green hogged fuel should be considered, rather than attacking the pollution problem at the stack with costly pollution control equipment. Wood gasification units, fuel preparation of sizing, and drying are all very possible and practical approaches both to direct firing and to firing of steam boilers. All of the processes that are currently being developed for direct firing will have future application for clean firing of boilers, as well as providing direct-fired process heat.

Direct-Fired Veneer Dryers at SWF Plywood Company

System Description

SWF Plywood Company, a subsidiary of Southwest Forest Industries, currently operates 16 veneer dryers at five manufacturing complexes in Oregon. Ten of these dryers are fired by nine suspension, direct wood-fired systems. An SWF internal energy study in 1976 revealed that some 830 million ft^3 (23.5 million m^3) of natural gas replacement (in Btu equivalence) was gained through direct wood firing. Approximately 60 percent of all energy used, exclusive of electricity, was derived from wood wastes generated in the manufacture of plywood.

Direct-firing concepts at SWF operations evolved following installation in 1972 of a sanderdust burner in conjunction with a wigwam burner to meet emission standards. Two units were installed in 1973-74 at former Carolina Pacific Plants, and seven units were installed in 1974-75 under the newly formed SWF Plywood Company's direction. All nine units are suspension type burners using finely ground fuel with maximum size of 5/64-in (0.198 cm). The plants where these units are located all receive veneer that is shipped in from company-owned or outside veneer mills. Wood waste fuel is made readily available at each location as a byproduct of the plywood production process. After processing, the wood waste fuel has an average moisture content of 2 to 4 percent and an average heat value of 8500 Btu/lb (19.77 MJ/kg).

In plywood manufacturing, there is roughly an 18- to 19-percent waste factor. About 180 to 190 pounds (81.64 to 86.18 kg) of dry wood waste is produced per 1000 ft^2 (92.90 m^2) of ⅜-in (0.95 cm) finished plywood from standard dimensions of veneer. The fuel mix can vary depending upon the degree of finishing done at the plant.

At 8500 Btu/lb (19.77 MJ/kg), the waste generation rate described in the previous paragraph equates to 1530 to 1616 Btu/ft^2 (17.4 to 18.4 MJ/m^2) of ⅜-in (0.95 cm) production. This Btu factor is very important in the analysis of the dry fuel direct-fired system. Source testing data gathered on an Energex unit in December 1977 revealed that 1630 lb/hr (0.205 kg/s) of fuel were being used to dry 12,300 ft^2 (1142.7 m^2) of 0.1-in (0.25 cm) Douglas fir veneer [⅜-in (0.95 cm) basis] input rate. This analysis, shown in Table 7, reveals that the heating value from plywood waste is sufficient to dry the plywood completely using a direct-fired veneer dryer.

Fuel requirements increase with the drying of wetter, thicker woods and/or cooler ambient temperatures. A review of annual SWF operations shows excess fuel being generated in the summer months tapering to a slight deficit (3 to 5 percent) in mid-winter. Current goals are to achieve wintertime self-sufficiency of fuel through increasing system efficiencies.

Emission Testing

Good emissions data needs to be developed for direct-fired systems. The data gathered should define the system's environmental impact and also should enable the owner to provide maximum efficiencies and production levels and minimum capital requirements for environmental control.

The need for data occurred when the preliminary Oregon emission guidelines directed the SWF direct-fired system to meet the 10-percent-average, 20-percent-maximum, veneer-dryer opacity standard. Also included in the guidelines was a particulate emissions limitation of 0.1 gr/scf (0.229 g/m^3) at 12-percent CO_2. The required test method was EPA Method No. 5 with a backup filter. Testing locations on the unit also were suggested. Data was needed to determine if the system(s) were properly understood and defined, if the stated test methods were applicable, and if the emissions were typical of veneer dryer emissions for control purposes.

Data gathered on the test unit in 1976 has provided SWF with the information necessary to implement a comprehensive program potentially able to reduce former emission levels by 50 percent, while improving fuel use efficiency and maintaining production levels. Opacities on the test unit have not yet been brought down to the 10-percent average level but have been reduced significantly, with the potential identified for further reduction prior to control system contemplation. Table 8 is a comparison of test results showing the emission reduction benefit already gained. Low levels of CO_2 in the most recent (1977) data revealed a possibility for further improvement of combustion efficiencies through the control of combustion air. Instrumentation has now been installed to balance fuel and combustion air input. Fuel usage rates are being monitored to check overall efficiency impacts. Increased HC reductions also are anticipated as a result of 100-percent recirculation of the dryer dry-end emissions to the burner.

Analysis of the emission particulate revealed, as expected, that emissions from direct-fired systems are typical of the emissions from steam or gas-fired veneer dryers: there is a definite wood combustion component

Table 7. Analysis of Heat Use and Fuel Balance for SWF Direct-Fired Dryer

Heat Use

1. 1630 lb/hr fuel × 8500 Btu/lb = 13,855,000 Btu/hr input
2. 13,855,000 Btu/hr input ÷ 12,300 ft^2 production = 1126 Btu/hr/ft^2
3. Btu in recirculating gas flow = 3,500,000 Btu/hr
4. Recirculation 3,500,000 Btu/hr ÷ 12,300 ft^2 = 284 Btu/hr/ft^2
5. Total Heat Use = 1126 Btu/hr/ft^2 + 284 Btu/hr/ft^2
   = 1410 Btu/hr/ft^2

Fuel Production

1. 12,300 ft^2/hr production × 0.85* = 10,455 ft^2/hr finished plywood
2. 10,455 ft^2/hr finished wood × 180 lbs fuel/1000 ft^2
   = 1880 lb/hr fuel produced

Fuel Balance

1880 lb/hr produced − 1630 lb/hr used = + 250 lb/hr surplus fuel

*Finished veneer factor

Table 8. Veneer Dryer Emission Data Comparison

October—1976	(Average Of Two Tests—Production Rate 14,000 ft^2/hr)		
	Inlet	Return	Atmosphere
Temp (°R)	1,367	760	760
Flow (scfm)	17,812	8,670	13,481
CO_2 (%)	5.45	4.3	4.3
H_2O (%)	15.2	19.8	19.8
Grains/scf	0.1495	0.183	0.183
Emissions (lb/hr)	22.64	13.60	21.15
Average Emission Rate		1.51 lb/1000 ft^2 veneer	

December—1977	(Average Of Three Tests—Production Rate 12,680 ft^2/hr)		
	Inlet	Return	Atmosphere
Temp (°R)	1,329	801	817
Flow (scfm)	18,761	10,111	10,405
CO_2 (%)	3.37	2.3	2.3
H_2O (%)	8.6	12.1	12.1
Grains/scf	0.1013	0.0952	0.0952
Emissions (lb/hr)	16.35	8.16	8.49
Average Emission Rate		0.67 lb/1000 ft^2 veneer	

in the exhaust gases. Air flow velocities are sufficient to keep the finer particles in suspension and in the recirculation flow. Laboratory analyses have verified that a significant amount of combustion particulate is impinged upon the veneer surface. This takes place on the wet veneer in the dryer green zone.

This system has three built-in emission control features, each of which should be optimized prior to adding on emission controls:

- Up to half of the exhaust gas is kept in recirculation
- Roughly half of the condensible HC is destroyed from the return flow in blending, or 25 percent of total condensible HC
- A total of 15 to 20 percent particulate is dropped out in the dryer and/or impinged upon the veneer.

The data shows that the direct-fired system (operated at peak efficiencies—lowest fuel usage per unit of production) can operate within the compliance emission rates for a hogged fuel boiler-steam dryer system. Table 9 contains theoretical emission rates (at compliance) calculated for a hogged fuel boiler-steam dryer unit on a pounds-of-emission per square foot of ⅜-in (0.95 cm) plywood produced basis. The hogged fuel boiler analysis is based upon industry averages reported by the American Plywood Association in June 1975, which were: 133 pounds (60.5 kg) dry hogged fuel required to produce 1,000 pounds (453.5 kg) of steam; and 2,400 pounds (1088.6 kg) of steam required to dry 1000 ft^2 (92.90 m^2) of ⅜-in (0.95 cm) Douglas fir veneer.

A comparison of Table 9 with the 1977 emission rate of the direct-fired systems in Table 8 shows that emissions problems caused by direct firing are not as bad as stack opacities might indicate. The key to lower emissions is in the unit efficiencies. The less fuel that is required to generate needed heat results in less ash than is created in combustion. The more dryer emissions are recirculated from the HC-producing dryer zones, the greater the level of hydrocarbon destruction.

When compared with boiler-steam dryer units, the direct-fired unit produces fewer emissions in terms of pounds per unit of production. However, to achieve optimum results, the system must be operating efficiently within a carefully controlled combustion regime. And even under these conditions, exhaust opacity standards may be difficult to meet.

The direct-fired system has the following advantages:

- Fossil fuel replacement
- Solid waste utilization for energy
- High-efficiency heat utilization
- A low emission rate per unit of production.

Other observations concerning the operation of direct-fired systems include:

- Fewer dryer fires at higher operating temperatures
- Easier dryer cleaning, requiring only a water rinse as opposed to the use of caustic chemicals
- Improved veneer gluing characteristics.

Table 9. Hogged Fuel Boiler Steam Dryer Analysis

Boiler-Fuel Requirements

$$\frac{133 \text{ lb dry fuel}}{1000 \text{ lb steam}} \times \frac{2400 \text{ lb steam}}{1000 \text{ ft}^2 \text{ veneer}} \times \frac{12{,}300 \text{ ft}^2 \text{ veneer}}{\text{hr}} = \frac{3{,}925 \text{ lb dry fuel}}{\text{hr}}$$

Assuming a 13-percent extra heat demand to remove 50 percent moisture in fuel:[a]

$$\frac{3{,}925 \text{ lb dry fuel}}{\text{hr}} \times 1.13 = \frac{4{,}435 \text{ lb dry fuel}}{\text{hr}}$$

Boiler-Exhaust Rate

At 50-percent excess air, 11,543 scf combustion gases is produced from 100 lb dry fuel:[a]

$$\frac{11{,}543 \text{ scf}}{100 \text{ lb fuel}} \times \frac{4{,}435 \text{ lb fuel}}{\text{hr}} \times \frac{1 \text{ hr}}{60 \text{ min.}} = \frac{8{,}532 \text{ scf}}{\text{min.}}$$

Boiler-Compliance Loading at 12-percent CO_2

$$\frac{0.1125 \text{ grains}}{\text{scf}} \times \frac{8{,}532 \text{ scf}}{\text{min.}} \times \frac{60 \text{ min.}}{\text{hr}} \times \frac{1 \text{ lb}}{7000 \text{ grains}} = \frac{8.3 \text{ lb}}{\text{hr}}$$

Steam Dryer-HC Emission Rate[b]

$$\frac{0.56 \text{ lb}}{1000 \text{ ft}^2 \text{ veneer}} \times \frac{12{,}300 \text{ ft}^2 \text{ veneer}}{\text{hr}} = \frac{6.9 \text{ lb}}{\text{hr}}$$

Assuming 50-percent collection efficiency to meet 10-percent average opacity:

$$\frac{6.9 \text{ lb}}{\text{hr}} \times 0.5 = \frac{3.45 \text{ lb}}{\text{hr}}$$

System Total

$$\frac{8.3 \text{ lb}}{\text{hr}} + \frac{3.45 \text{ lb}}{\text{hr}} = \frac{11.75 \text{ lb}}{\text{hr}}$$

$$\frac{11.75 \text{ lb}}{\text{hr}} \times \frac{1 \text{ hr}}{12{,}300 \text{ ft}^2 \text{ veneer}} = \frac{0.955 \text{ lb}}{1000 \text{ ft}^2 \text{ veneer}}$$

[a]Junge, David C., *Boilers Fired with Wood and Bark Residues,* Research Bulletin No. 17, Forest Research Laboratory, Oregon State University, November, 1975.

[b]Adams, Donald F., *Evaluation of Veneer Dryer Emissions,* American Plywood Association, February, 1971.

The increased air flow of the direct-fired system raises pressure levels and necessitates tighter seals and baffles to prevent fugitive emissions. But the more difficult problem is exhaust stack opacity. The future of the direct-fired dryer may need to be carefully weighed against opacity standards and their enforcement.

Case Study: Pilot Studies for Particulate Control of Hogged Fuel Boilers Fired with Salt Water-Stored Logs

Introduction

Firing salt-laden wood residue in hogged fuel boilers results in increased particulate emissions and high visual opacities. Georgia-Pacific Bellingham has very little control of the salt content in the fuel because a varying amount of hogged fuel is purchased from sources that utilize salt water storage of logs.

Salt makes up about 25 to 50 percent of the particulate loading from the hogged fuel boilers at G-P Bellingham and as high as 65 to 90 percent of the particulate from boilers at other Northwest mills. Salt particulate is submicron in size and consequently difficult to collect. The total grain loading must be reduced to less than 0.05 gr/scf (0.115 g/m^2) to reduce stack opacity to 20 percent.

Hogged Fuel Boiler Facilities

The hogged fuel boiler system at G-P Bellingham consists of four Sterling boilers built by Babcock and Wilcox Co. in 1937 to 1940. They are of the Dutch oven design with two cells per boiler. Each boiler has three steam drums and one mud drum, combustion air preheaters, but no economizers. They are rated at 55,000 lb/hr (6.92 kg/s) of steam when hogged fuel is fired alone, or 70,000 lb/hr (8.8 kg/s) each when oil is fired in combination with hogged fuel.

Boilers 1, 2, and 3 have Western Precipitation multiclone for particulate removal. No. 4 boiler has had its Dutch oven blanked off and is currently fired with natural gas or oil (no hogged fuel). All four boilers exhaust through a common breeching to a single stack (see Figure 12).

The primary source of hogged fuel for these boilers is residue from salt-water-floated logs from Canadian lumber mills. Other fuel is trucked in from local sawmill operations or supplied by the mill's barking plant. Clarifier sludge is burned in the boiler about one shift each day.

The hogged fuel has not been classified or dried. Severe variations in moisture content of the hogged fuel require oil to be fired at times to ensure combustion.

Emission Studies

Particulate tests were performed in January 1977 using an EPA Method 5 particulate sampling train to collect design data for scrubber selection. Subsequently, a particle size distribution was made using a high resolution cascade impactor designed and built by Phillip A. Nelson. Particulate and particle size distribution were tested at a point upstream of the main stack, after the multiclones; 30 to 35 percent of the total particulate is smaller than 1 μm in size. (Refer to Figure 13). See Table 10 for the test results from the particulate testing. In order to use the particle size distribution as a basis for scrubber selection, it was necessary to test when salt content in particulate emissions was at its worst. To simulate this condition, salt was added to the fuel being burned at a rate of 0.5 percent by weight on a dry fuel basis.

Initial Investigation of Particulate Collectors and Pilot Selection

Five types of particulate collectors were investigated as possible devices for bringing the hogged fuel boilers into compliance. These were: (1) wet scrubbers (both low-energy impaction type and variable-throat venturi), (2) gravel bed scrubbers, (3) dry precipitators, (4) wet precipitators, and (5) baghouses.

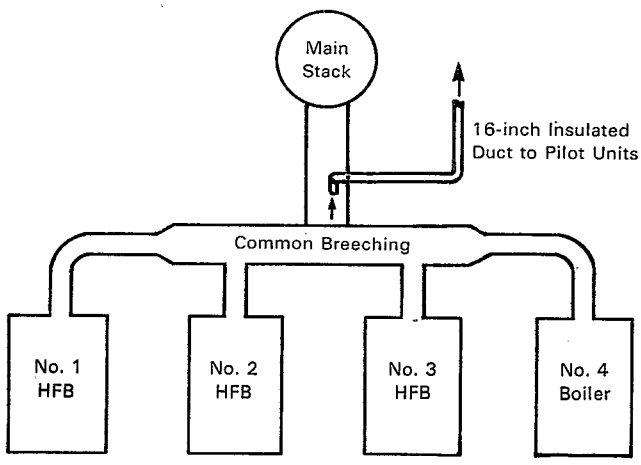

Figure 12. Hog Fuel Boiler Layout

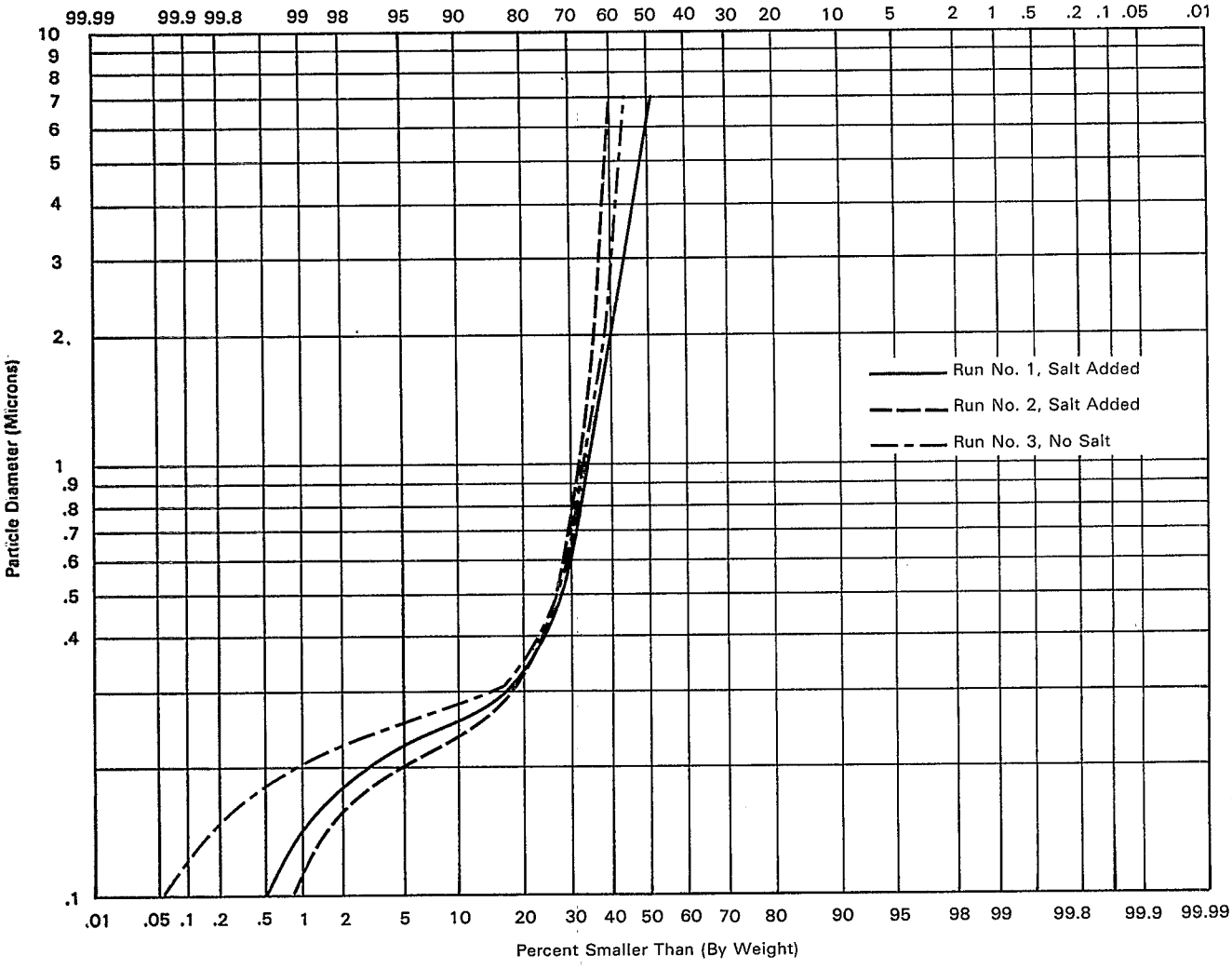

Figure 13. Particle Size Distribution HFB

Table 10. Particulate Testing Results

Item	Units	1-11-77	1-11-77	1-12-77
Boilers Operating During Test		No. 1,2,3	No. 1,2,3,4	No. 1,2,3
Total EPA Particulate Dry Corrected to 12% CO_2	grains/scf	0.79	0.54	0.30
Orsat Analysis: CO_2/O_2	%	13/5	10.4/6.7	8/11.5
Stack Air Flow	acfm	172,843	204,724	161,265
(@ 70°F, 29.92" Hg)	scfm	101,615	120,842	98,963
Stack Temperature	°F	440.6	437	479
Steam Production Rate (avg. of all tested boilers)	10^3lb/hr	50	50	32
Excess Air	%	25.0	44.1	118.0
NaCl Content in Particulate	%	52.4	NA	NA

Note: Fuel burned during all three tests was purchased hogged fuel; no barking plant refuse or clarifier sludge.
Operating conditions for all three tests: gas and oil were not being burned and the cinder reinjection fans were off.

A survey of pilot work performed at other mills and of equipment currently under construction (or in operation) showed that all of the collector types already had been tested and/or selected for use except the Union Carbide Corporation Electro-Tube precipitator. This device was invented by Air Pollution Systems,

Tukwila, Washington and is exclusively licensed to Union Carbide Corporation. This device is a wetted-wall pipe type precipitator with a patented electrode geometry. It was decided to pilot test this unit, since it had many potential advantages, such as low space requirements, minimal pressure drop, and very low electrical usage.

Additional information was required for the economic evaluation of baghouses. Two bag fabrics were recommended: Nomex® and Teflon®-coated Fiberglas. Fiberglas baghouses have been operated for over a year and a half. Nomex®, however, was not being used in a baghouse operating on hogged fuel boilers fired with salt-laden fuel. Because there would be an economic incentive to use Nomex® if it had a significantly longer bag life than the Fiberglas, a Nomex® baghouse was pilot tested to allow Dupont to predict Nomex® bag life. Other reasons for running this pilot unit were to: (1) confirm an air-to-cloth (A/C) ratio of 3.25:1 (air-to-cloth is the ratio of acfm treated gas to the fabric surface area in ft^2) with the unit being cleaned on-line; (2) measure collection efficiency; and (3) collect enough dust to evaluate settling rates, etc.

Electro-Tube

Description of the Pilot Plant

The Union Carbide Corporation Electro-Tube is a two-stage electrostatic device that combines a wetted-wall electrostatic precipitator with high-intensity particle precharging. Particles are charged at various disks and are continuously attracted to the tube wall by the field between the electrode and the tube wall. The Electro-Tube is a pipe type electrostatic precipitator with wetted walls that has proved to be effective where the resistivity or stickiness of the dust prohibits the use of a conventional unit. The electrode geometry provides a more stable corona discharge system that results in operating field levels of three to five times higher than that of conventional electrostatic precipitators. The result is a higher charge on the particles, and consequently, a greater force of attraction to the anode. This happens because the center electrode is a metal rod, not a wire with a weight attached. The rod is relatively rigid (compared with the wire and weight). Thus, a close tolerance on the gap between the electrode and tube can be maintained. The smaller that gap, the greater the electrical field for constant electrical usage.

The Electro-Tube was tested for a maximum gas flow rate of 800 acfm (0.377 m^3/s) per tube. The wetted-wall anode is 10 ft (3.048 m) long by 12 in (30.48 cm) in diameter. These tube dimensions are the same for both the pilot unit and full-size installation. Thus, a scale-up to a full-size unit would mean simply increasing the number of tubes for a specific application. A 2-in (5.08 cm) diameter driving field electrode with four different discharge electrode configurations was used for testing.

Testing Procedure

Fourteen sets of inlet and outlet grain loading tests were performed with varying electrode configurations, voltage-current levels, and weir overflow rates (Table 11). Two inlet and outlet tests each were run at gas flow rates of 500, 625, and 750 acfm (0.236, 0.294, and 0.354 m^3/s) with all other variables constant. These tests were to determine the effect of gas flow rate on performance.

Eleven of the 14 sets of tests were performed by G-P personnel using an EPA Method 5 particulate sampling train. Since only one sampling train was available, tests were not concurrently run at the inlet and outlet to the Electro-Tube precipitator. This introduced some uncertainty in the evaluation of the Electro-Tube. Air Pollution Systems (APS) was capable of providing simultaneous inlet-outlet sampling; these are identified in Table 11 as tests 12, 13, and 14.

Discussion of the Particulate Test Results for the Electro-Tube

Actual Electro-Tube outlet grain loadings ranged from 0.00087 gr/scf to 0.0214 gr/scf (0.0019 to 0.049 g/m^3) (see Table 11). Corrected outlet loadings ranged from 0.0019 gr/scf (.004 g/m^3) at 12 percent CO_2 to 0.044 gr/scf (0.100 g/m^3) at 12 percent CO_2. This was accomplished with near zero opacity.

Grain loadings corrected to 12 percent CO_2 are useful for compliance testing, but not for determining the true collection efficiencies. Because of this, collection efficiencies discussed here are calculated on the basis of uncorrected grain loadings. Calculated efficiencies for 12 of the 14 tests ranged from 95.6 percent to 99 percent.

Measured pressure drops across the Electro-Tube (from inlet sampling point to the outlet sampling point) ranged from 0.3-in (0.76 cm) H_2O to 1-in (2.54 cm) H_2O, averaging 0.68 in (1.73 cm).

Water used for particulate removal from the Electro-Tube ranged from 1.33 to 6 gpm/1000 acfm (0.178 to 0.802 $m^3/s/1000\ m^3/s$) of treated gas. Drain fittings were not adequate on the pilot unit and plugged. Increasing water flow prevented a buildup of particulate on the tube wall, and resulted in a reduced sparking rate. It can be speculated that adequately designed drain fittings would have allowed good operation at a water flow rate of 2 gpm/1000 acfm (0.267 $m^3/s/1000\ m^3/s$) of treated gas.

Electrical requirements for the Electro-Tube itself would be approximately 100 hp (74.6 kW) for a system large enough to treat the gases from G-P's hogged fuel system. Electrical requirements of pumps and fans are not included.

Baghouse

Description of the Pilot Plant

Mikro Pul Corporation supplied a baghouse for G-P's pilot trial. This was a pulse-jet baghouse fitted

Table 11. Electro-Tube Test Data

Date Set Test No.	acfm	Voltage kV	Amperage MA	Temp. Duct °C	Grain* Loading gr/scf	Uncorrected Grain Loading gr/scf	Uncorrected % Eff.	gpm Weir	Comments
1.....	750	78	4.3	165 90	0.3311 0.0439	0.1617 0.214	86.7	1.0	
2.....	750	78	4.3	183 93	0.7036 0.018	0.3446 0.0088	97.4	1.0	
3.....	750	78	4.3	167 87	0.9307 0.00994	0.4708 0.00503	98.9	1.8	Plugged Multiclone
4.....	750	78	4.3	164 84	0.502 0.0096	0.254 0.0047	98.1	1.8	Plugged Multiclone
5.....	500	90	3.6	164 84	0.3245 0.0073	0.137 0.0031	97.7	1.8	
6.....	625	76	2.3	166 94	0.2608 0.0060	0.1898 0.0042	97.8	3.0	
7.....	625	76	2.3	166 95	0.2880 0.0092	0.1824 0.0058	96.8	3.0	
8.....	750	76	2.3	178 111	0.2487 0.0045	0.1976 0.0035	98.3	3.0	Data in Question
9.....	750	76	2.3	171 95	0.0361 0.0110	0.0274 0.0079	71.2	3.0	Data in Question
10.....	500	76	2.3	102 72	0.1859 0.0027	0.1219 0.0013	98.9	3.0	Salt Water Added
11.....	500	76	2.3	116 72	0.1664 0.0019	0.0906 0.00087	99.0	3.0	Salt Water Added
12.....	790	64	0.9	192 110		0.2279 0.008	96.2	3.0	Salt Water Added; Boilers Not At Maximum Steam Production
13.....	680	75	1.1	185 89		0.4167 0.0011	99.7	3.0	Salt Water Added
14.....	739	74	1.5	192 83		0.1991 0.0088	95.6	3.0	Salt Water Added

*Corrected values to 12% CO_2

with 100 standard galvanized support cages and Nomex® felt bags. The pilot plant was designed for a gas flow rate of 3000 to 3500 acfm (1.42 to 1.65 m^3/s).

Testing Procedure

Nine sets of inlet and outlet grain loading tests were performed to verify cleaning efficiencies and also to determine the air-to-cloth ratio at which the unit could be operated with a stable presure drop. These tests were performed while the unit was being cleaned.

To verify feasibility of off-line cleaning during the second phase of testing, the baghouse was operated for a period of time with its compressed air shut off. Air flow was then stopped and the unit was cleaned. Pressure drop readings were recorded while the baghouse was operating and after cleaning periods.

One bag was removed from the unit each week and was returned for physical tests to project bag life on the Nomex® in a full-scale installation.

Discussion of Test Results for the Baghouse

Actual outlet grain loadings ranged from 0.00046 to 0.015 gr/scf (0.0010 to 0.034 g/m^3) (see Table 12). Corrected outlet loadings ranged from 0.00077 to 0.028

Table 12. Baghouse Test Data

Date Set Test No.	ACFM	Grain Loading gr/SDCF (actual)	Grain Loading gr/SDCF @ 12% CO_2	Collection Efficiency % (actual)	A/C Ratio acfm/ft^2
1	2781	0.7369 0.0043	1.4737 0.0083	99.42	2.95
2	3673	0.3849 0.0150	0.5371 0.0281	96.10	2.97
3	3774	0.244 0.00046	0.3400 0.00077	99.8	4.06
4	3432	0.4301 0.0015	0.6144 0.00230	99.65	3.69
5	3047	0.2396 0.0060	0.356 0.010	97.5	3.30
6	2979	0.567 0.0049	0.756 0.009	99.14	3.23
7	3214	0.196 0.0099	0.2868 0.0142	94.95	4.11
8	2924	0.242 0.003	0.417 0.0046	98.76	3.74
9	2753	0.335 0.0012	0.529 0.0016	99.64	4.715

gr/scf (0.0017 to 0.064 g/m^3) at 12 percent CO_2. Stack opacity was essentially zero during the 7-week pilot run, except for a few hours during startup periods. During startup, water vapor was visible from the stack until the system was brought up to operating temperature.

Collection efficiencies based on actual inlet and outlet grain loadings ranged from 94.9 to 99.8 percent. These efficiencies corresponded to no visible discharge.

On-line operation of the baghouse at an air-to-cloth (A/C) ratio of 3.3:1 or less resulted in a stable pressure drop of about 2.5-in (6.35 cm) H_2O across the tube sheet. An increasing pressure drop resulted when the A/C ratio was increased above 3.3:1.

Off-line cleaning of the baghouse was performed at A/C ratios as high as 5.9:1. Adequate cleaning of the bags was achieved, which meant that pressure drop could be maintained at this higher A/C ratio. It should be pointed out that off-line cleaning requires additional valving hardware to isolate modules during the cleaning cycle.

Dupont performed physical tests on the test bags and projected a baglife of 18 to 24 months for Nomex® in the service of salt-laden fuel fired in a hogged fuel boiler. Three factors are detrimental to the use of Nomex® in this service: (1) a temperature of 385 to 400°F (196 to 204.4°C) is recommended as the maximum continuous temperature; (2) Nomex® is subject to chemical attack from SO_2 in the flue gas; and (3) the bag life of Nomex® seems to be shortened by chlorides.

Summary and Conclusions

Union Carbide Corporation Electro-Tube

Overall performance of the pilot unit was excellent. Electrical costs are only a fraction of that required for any other conventional particulate collection device. Pressure drop is nominally 1-in (2.54 cm) H_2O, again less than any other competing device. It is expected that a full-scale system would perform equally well. The principal drawback to this design involves construction materials, since most metals experience extreme corrosion when exposed to salt water at 400°F (204.4°C). Consultants recommended Inconel 625, but this material would double the cost for a baghouse.

Nomex® Baghouse

Fabric filtration has been satisfactorily established as a pollution control device for hogged fuel boilers with salt-laden fuel. G-P's pilot work verified this. Nomex® bag life is expected to be approximately

the same as Fiberglas. However, temperature, SO_2 concentrations, and chlorides must be controlled to allow Nomex® to be used for this application.

In summary, it was demonstrated that both Electro-Tube and Nomex® baghouse devices would reduce particulate emissions to required levels. Each had its unique advantages and disadvantages, and individual peculiarities. Final selection of a full-sized installation would, of course, require site-specific considerations.

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Introduction
Water Pollution Control

The forest products industry is a resource-intensive industry relying on the ability of land and water to produce timber. The industry's impact on water quality results from its land management and timber harvesting practices and from its manufacturing processes. In both areas, the industry must comply with pollution control regulations enforced by the U.S. Environmental Protection Agency and state-level environmental control agencies acting under the guidelines of the nation's Clean Water Act.

To assist the industry in planning and implementing pollution control measures, the U.S. Environmental Protection Agency and the Forest Products Research Society sponsored pollution control seminars held in Dallas, Texas on September 28-29, 1977, and in Portland, Oregon on April 4-6, 1978. This publication contains materials presented at the seminars and is intended to serve as a reference to the industry and others concerned with the approaches and technologies that will enable the industry to meet its pollution control obligations.

The papers presented by regulatory officials, researchers, and industry personnel are reviewed in this publication. As such, no attempt is made to provide a comprehensive picture or cookbook approach to water pollution control problems in the industry. Rather, the contents of this publication represent a range of thinking and activities relating to water quality management by the forest products industry.

Appended is a list of references available on the subjects covered.

The Clean Water Act

The Clean Water Act of 1977 (PL 95-127) is an amended version of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500). Its objective is to restore and maintain the chemical, physical, and biological integrity of America's waters. The Act sets a national goal of eliminating man-caused pollutant discharges into navigable waters by 1985, with an interim goal of swimmable, fishable water quality by 1983.

Pollutants targeted by the Clean Water Act are broadly categorized as either point sources or nonpoint sources. Point sources are pollutants discharged at discrete locations, such as pipe and channel outfalls. Nonpoint sources are more pervasive and include such pollutants as overland runoff and underground seepage leading to contamination of surface and groundwaters.

Point sources of pollution are controlled through the National Pollutant Discharge Elimination System (NPDES), a permits program administered by the U.S. Environmental Protection Agency (EPA) through state-level environmental agencies. The Clean Water Act also established procedures for setting effluent limitations and standards for point sources.

Point Source Control

When the PL 92-500 was signed into law in October 1972, there were 27 categories of point sources for which effluent limitations and standards were to be established by the EPA Administrator. The first regulations affecting the primary wood products industry (timber products processing) appeared in the *Federal Register* in April 1974 and January 1975. Pretreatment regulations for existing sources in the timber products processing point source category appeared in the *Federal Register* in December 1976.

These regulations set forth effluent limitations for existing sources, new source performance standards, and pretreatment standards for 15 subcategories of the industry. Except for the subcategories that include wood preserving plants, the pollutant parameters addressed are biochemical oxygen demand (BOD), suspended solids, and pH. For the wood-preserving segment of the industry, chemical oxygen demand (COD), phenols, oil and grease, and pH are the parameters.

After these regulations were promulgated, a civil action suit was brought by the Natural Resources Defense Council (NRDC), Environmental Defense Fund (EDF), the National Audubon Society, and Businessmen for the Public Interest, Inc. in the U.S. District Court for the District of Columbia. As a result of this action, a Settlement Agreement was made on June 7, 1976, which has serious ramifications for industry and the EPA. The Agreement charges EPA with the task of developing and promulgating effluent limitations guidelines and standards for 65 toxic substances; this is to be done for 21 major industry categories, of which timber products processing is the first on the list.

Table 13 lists the 65 chemical substances for which effluent limitations and guidelines and new source performance and pretreatment standards are to be developed. Since the list of the 65 chemical substances is somewhat generic, EPA was faced with the problem of how to identify specific chemical substances that would meet the requirements for addressing the 65 substances listed in the Settlement Agreement. Table 14 lists 129 specific representative chemical substances. Table 15 is a list of those Standard Industrial Classification (SIC) codes in the timber products processing industry that are to be addressed in carrying out the work under the Agreement.

The timber products processing industry was the first studied by EPA under the Settlement Agreement. The work that is being done for the timber products processing category by EPA under the Settlement Agreement is divided into three major components: (1) a technical study, (2) an economic impact analysis study, and (3) environmental impact studies. The schedule set forth in the Agreement called for EPA to retain a contractor for technical studies of the timber products processing industry no later than June 30, 1976. This was done. The technical work was completed by Environmental Science and Engineering, Inc. of Gainesville, Florida. Their report was delivered to EPA on July 29, 1977 and has been circulated to other Federal offices, states, industry, and public interest groups for review

Table 13. Settlement Agreement Pollutants

Acenaphthene	Cyanides	Mercury & Compounds
Acrolein	DDT & Metabolites	Napthalene
Acrylonitrile	Dichlorobenzene	Nickel & Compounds
Aldrin/Dieldrin	Dichlorobenzidine	Nitrobenzene
Antimony & Compounds	Dichloroethylenes	Nitrophenols
Arsenic & Compounds	2,4-Dichlorophenol	Nitrosamines
Asbestos	Dichloropropane & Dichloropropene	Pentachlorophenol
Benzene	2,4-Dimethylphenol	Phenol
Benzidine	Dinitrotoluene	Phthalate Esters
Beryllium & Compounds	Diphenylhydrazine	Polychlorinated Biphenyls
Cadimium & Compounds	Endosulfan & Metabolites	Polynuclear Aromatic Hydrocarbons
Carbon Tetrachloride	Endrin	Selenium & Compounds
Chlordane	Ethylbenzene	Silver & Compounds
Chlorinated Benzenes	Fluoranthene	2,3,7,8-Tetrachlorodibenzo-P-Dioxin
Chlorinated Ethanes	Haloethers	Tetrachloroethylene
Chloralkyl Ethers	Halomethanes	Thallium & Compounds
Chlorinated Napthalene	Heptachlor & Metabolites	Toluene
Chlorinated Phenols	Hexachlorobutadiene	Toxaphene
Chloroform	Hexachlorocyclohexane	Trichloroethylene
2-Chlorophenol	Hexachlorocyclopentadiene	Vinyl Chloride
Chromium & Compounds	Isophorone	Zinc & Compounds
Copper & Compounds	Lead & Compounds	

and comment. An economic analysis of the industry is being conducted by Arthur D. Little of Cambridge, Massachusetts.

Under the current schedule in the Settlement Agreement, EPA must propose regulations affecting the timber products processing category by September 30, 1978 and must promulgate final regulations by March 30, 1979.

The information gathered to date indicates that considerable effort is being made by the wet process hardboard, insulation board, and wood preserving segments of the industry to conserve water and to recycle and reuse process wastewater. In addition to pollution control, some of the incentives for re-examining water and wastewater management practices in the plants have been the limited availability of fresh water, higher energy and sludge disposal costs, and, for indirect dischargers, industrial cost recovery fees and increased user charges. Some of the plants are finding that the cheapest wastewater control option is complete recycle of wastewater or no discharge.

An economic impact analyst will be studying the impact of each level of pollution control technology applied to the industry, including such impacts as potential plant closures, employment, profitability, return on investment, and international competition. Studies of the environmental impact of the pollutants being discharged by the industry will focus basically on those water bodies in various geographical regions of the country that might be most severely impacted by the industry's discharges. As EPA approaches its rulemaking deadlines, it will continue to seek comments from the industry. Communications have been established with the industry through the efforts of the American Wood Preservers Association, the American Wood Preservers Institute, the National Forest Products Association, the American Board Products Association, the Southern Furniture Manufacturers Association, and the Forest Products Research Society.

Nonpoint Source Control

Section 208 of the Clean Water Act is designed to produce areawide waste treatment management planning to assure adequate control of sources of water pollution in each state. Activities not covered by the point source control program are addressed by the nonpoint source planning aspects of Section 208.

Point and nonpoint sources of pollution can be differentiated by comparing their control methods. Most nonpoint sources are best handled by using land management techniques rather than by treating the effluent. In other words, it's more practical and economical to treat nonpoint sources where the rain hits the ground than to collect the runoff and send it to a treatment plant.

Nearly all nonpoint source pollutants are storm-generated and most are predominantly rural in nature. EPA has arrived at eight categories of nonpoint sources: agriculture, silviculture, construction, mining, hydrologic modifications, practices primarily affecting groundwater, residual waste disposal, and urban runoff. While construction and urban runoff are major factors in urban areas, the remaining categories are more prevalent in rural areas.

EPA realizes that the magnitude of the nonpoint source problems is immense—possibly greater than the total problem caused by point sources. It is estimated that 15 percent of the nation's waters are failing to

Table 14. Specific Chemical Substances to be Examined

1. acenaphthtne[a]
2. acrolein[a]
3. acrylonitrile[a]
4. benzene[a]
5. benzidine[a]
6. carbon tetrachloride[a]

Chlorinated benzenes[a]
7. chlorobenzene
8. 1,2,4-trichlorobenzene
9. hexachlorobenzene

Chlorinated ethanes[a]
10. 1,2-dichloroethane
11. 1,1,1-trichloroethane
12. hexachloroethane
13. 1,1-dichloroethane
14. 1,1,2-trichloroethane
15. 1,1,2,2-tetrachloroethane
16. chloroethane

Chloroalkyl ethers[a]
17. bis (chloromethyl) ether
18. bis (2-chloroethyl) ether
19. 2-chloroethyl vinyl ether

Chlorinated napthalene[a]
20. 2-chloronaphthalene

Chlorinated phenols[a]
21. 2,4,6-trichlorophenol
22. panachlorometa creosol
23. chloroform[a]
24. 2-chlorophenol[a]

Dichlorobenzenes[a]
25. 1,2-dichlorobenzene
26. 1,3-dichlorobenzene
27. 1,4-dichlorobenzene

Dichlorobenzidine[a]
28. 3,3′-dichlorobenzidine

Dichloroethylenes[a]
29. 1,1-dichloroethylene
30. 1,2-trans-dichloroethylene
31. 2,4-dichlorophenol[a]

Dichloropropane and dichloropropene[a]
32. 1,2-dichloropropane
33. 1,3-dichloropropylene
34. 2,4-dimethylphenol[a]

Dinitrotoluene[a]
35. 2,4-dinitrotoluene
36. 2,6-dinitrotoluene
37. 1,2-diphenylhydrazine[a]
38. ethylbenzene[a]
39. fluroanthene[a]

Haloethers[a]
40. 4-chlorophenyl phenyl ether
41. 4-bromophenyl phenyl ether
42. bis (2-chloroisopropyl) ether
43. bis (2-chloroethoxy) methane

Halomethanes[a]
44. methylene chloride
45. methyl chloride
46. methyl bromide
47. bromoform (tribromomethane)
48. dichlorobromoethane
49. trichlorofluoromethane
50. dichlorodifluoromethane
51. chlorodibromomethane
52. hexachlorobutadiene[a]
53. hexachlorocyclopentadiene[a]
54. isophorone[a]
55. napthalene[a]
56. nitrobenzene[a]

Nitrophenols[a]
57. 2-nitrophenol
58. 4-nitrophenol
59. 2,4-dinitrophenol[a]
60. 4,6-dinitro-o-creosol

Nitrosamines[a]
61. N-nitrosodimethylamine
62. N-nitrosodiphenylamine
63. N-nitrosodi-n-propylamine
64. pentachlorophenol[a]
65. phenol[a]

Pthalate esters[a]
66. bis (2-ethylhexyl) phthalate
67. butyl benzyl phthalate
68. di-n-butyl phthalate
69. di-n-octyl phthalate
70. diethyl phthalate
71. dimethyl phthalate

Polynuclear aromatic hydrocarbons[a]
72. 1,2-benzanthracene
73. benzo (a) pyrene (3,4-benzopyrene)
74. 3,4-benzofluoranthene
75. 11,12-benzofluoranthene
76. chrysene
77. acenaphthylene
78. antracene
79. 1,12-benzoperylene
80. fluorene
81. phenanthrene
82. 1,2,5,6-dibenzanthracene
83. indeno (1,2,3-cd) pyrene
84. pyrene
85. tetrachloroethylene[a]
86. toluene[a]
87. trichloroethylene[a]
88. vinyl chloride (Chloroethylene)[a]

Pesticides and metabolites
89. aldrin[a]
90. dieldrin[a]
91. chlordane[a]

DDT and metabolites[a]
92. 4,4′-DDT
93. 4,4′-DDE (p,p′-DDX)
94. 4,4′-DDD (p,p′-TDE)

Endosulfan and metabolites[a]
95. a-endosulfan-Alpha
96. b-endosulfan-Beta
97. endosulfan sulfate

Endrin and metabolites[a]
98. endrin
99. endrin aldehyde

Heptachlor and metabolites[a]
100. heptachlor
101. heptachlor epoxide

Hexachlorocyclohexane[a]
102. a-BHC-Alpha
103. b-BHC-Beta
104. r-BHC (lindane)-Gamma
105. g-BHC-Delta

Polychlorinated biphenyls (PCB's)[a]
106. PCB-1242 (Arochlor 1242)
107. PCB-1254 (Arochlor 1254)
108. PCB-1221 (Arochlor 1221)
109. PCB-1232 (Arochlor 1232)
110. PCB-1248 (Arochlor 1248)
111. PCB-1260 (Arochlor 1260)
112. PCB-1016 (Arochlor 1016)
113. toxaphene[a]
114. antimony (Total)[a]
115. arsenic (Total)[a]
116. asbestos (Fibrow)[a]
117. beryllium (Total)[a]
118. cadmium (Total)[a]
119. chromium (Total)[a]
120. copper (Total)[a]
121. cyanide (Total)[a]
122. lead (Total)[a]
123. mercury (Total)[a]
124. nickel (Total)[a]
125. selenium (Total)[a]
126. silver (Total)[a]
127. thallium (Total)[a]
128. zinc (Total)[a]
129. 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD)[a]

[a]Specific compounds and chemical classes as listed in the consent decree.
Ambiguous compounds or classes of compounds are underlined.

Table 15. Timber Products Processing Industry Categories

SIC Code	Title
2411 ...	Logging Camps and Logging Contractors (Camps Only)
2421 ...	Saw Mills and Planing Mills, General
2426 ...	Hardwood Dimension and Flooring Mills
2429 ...	Special Purpose Sawmills, Not Elsewhere Classified
2431 ...	Millwork
2434 ...	Wood Kitchen Cabinets
2435 ...	Hardwood Veneer and Plywood
2436 ...	Softwood Veneer and Plywood
2439 ...	Structural Wood Members, Not Elsewhere Classified
2491 ...	Wood Preserving
2499 ...	Wood Products, Not Elsewhere Classified (Furniture Mills)
2661 ...	Building Paper and Building Board Mills (Hardboard Only)

meet water quality standards because of nonpoint source pollution and another 35 percent are equally degraded by a combination of point and nonpoint sources. The effects of these nonpoint sources will become more evident as pollution attributed to point sources is further reduced through applied control technology.

EPA's approach to nonpoint source pollution control has been to establish, by regulation, the concept of Best Management Practices (BMP's). These are defined as:

> ... a practice, or combination of practices, that is determined after problem assessment, examination of alternative practices, and appropriate public participation to be the most effective, practicable (including technological, economic, and institutional considerations) means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality goals.

Thus BMP's are broadly defined in terms of objectives rather than specific control activities. In adopting this approach, EPA has recognized four important facts:

- Essentially there is no one right way to prevent, manage, or control nonpoint source pollution problems.
- The same problem-solving techniques cannot be applied everywhere and produce the same results due to such uncontrollable factors as climate and geography.
- The physical environment together with legal, political, and institutional conditions differs from area to area—to such an extent as to make rigid Federal requirements for control inappropriate and unworkable.
- Successful management of nonpoint sources and of the 208 program must involve the continual integration of technical, administrative, and regulatory functions and skills.

For the most part, effective land management techniques are known and many are in daily use throughout the country. These will form the options from which BMP's will be chosen. As an example, the Soil Conservation Service, Forest Service, Soil and Water Conservation Districts, Extension Services, and a host of other Federal, state, and local agencies have worked for many years to develop land management techniques to keep the soil on the land. When these techniques are evaluated from the slightly different viewpoint of keeping the soil out of the water, they become BMP's.

Section 208 recognizes that technology alone may not be sufficient to achieve the goals of the Clean Water Act. In order to go beyond a technological assault on water pollution, major public policy questions must be addressed. It was with this foresight that Congress placed the local emphasis on Section 208 planning, involving locally elected officials and requiring extensive public participation in plan development.

Nonpoint Sources and Water Quality Research for Forest Management

Introduction

Research devoted to developing methods for controlling nonpoint source pollution from silvicultural activities is a very recent scientific endeavor. It grew out of an applied research area known as watershed management, which, in turn, had its origins in some very fundamental questions about how forests affected climate and streamflow.

Concern about the interaction between forests and water can be found throughout history, mostly regarding the influence of forests on floods. The theme "Protecting the forest is protecting the river" has been carried through time up to the nation's earliest efforts to regulate forest use for flood protection. A principal reason for establishing National Forests was to secure and protect the forested headwaters of the nation's river systems for flood-control purposes.

Controlling soil erosion through reforestation of abandoned farmland became an important research issue in the 1920's and 1930's. This concern was extended to investigations of the effect of timber harvesting on soil loss in steep terrain. Most of this research began in the eastern U.S. and the focus was on maintaining soil productivity, not water quality. As a result, soil losses generally were quantified in terms of tons lost per acre rather than in the concentration units typical of today's water quality standards.

Research that focused specifically on the relationship between silviculture and water quality did not begin until the late 1950's. In the Northwest, the research on the H.J. Andrews Experimental Forest and in the Alsea Basin Aquatic Resources Study were pioneering efforts to establish such relationships.

Today, within the framework of the Clean Water Act and its focus on nonpoint sources, there is increased concern regarding the impact of forest management practices on water quality. Attempts to regulate such practices have revealed a dearth of available information on which to base and justify control recommendations and policies. To expand upon available information, a number of studies have been initiated recently.

The EPA and the U.S. Forest Service have been involved principally in research programs presently underway. But the efforts to date have only begun to establish meaningful or usable information. Most experts agree that further research is needed—and most point to the specific need for cross-fertilization of research to develop better understanding of the linkage mechanisms that translate actual forest management practices to site-specific water quality impacts. Such understanding will not come easily.

The problems surrounding nonpoint source studies are related to their general context: forestry-related nonpoint sources are created within the context of a partially controllable system that is variable over space and time. With respect to water quality, forest lands can be characterized as follows:

- Day-to-day variations in water quality in undisturbed watersheds are substantial, particularly during periods of changing flows.
- Fluctuations in undisturbed systems may be as great as those in apparently similar, but disturbed, systems.
- Most water quality constituents identified as pollutants (with the exception of certain introduced chemicals) also occur naturally within the system.
- The pollutants discharged enter the water in a diffuse manner and, in many cases, at intermittent intervals.
- The extent of pollution is related, at least in part, to certain uncontrollable climatic events, as well as geographic and geologic conditions, and may differ greatly from place to place.
- The pollutants arise over an extensive area of land and are in transit overland before they enter receiving waters.

These factors, as well as natural variations in site characteristics and the cyclic nature of most silvicultural activities, contribute to the complexity of assessing man-induced pollution and then selecting appropriate controls.

EPA's Environmental Research Laboratory in Athens, Georgia, has been charged with the responsibility for developing total management and technological systems to control nonpoint source pollutants associated with forest products industry operations. However, EPA stresses that it is relying heavily on outside expertise and interagency agreements (particularly with the Forest Service) to meet this challenge.

Examples of Recent Research

One of the first steps taken in the EPA Athens Laboratory research program was to assess what is already known about the forest nonpoint source problem and, from that, to identify priority research needs. This assessment and identification was done for EPA under an interagency agreement with the U.S. Forest Service. It resulted in a report entitled *Non-Point Water Quality Modeling in Wildland Management: A State-of-the-Art Assessment.*[26,27] That document, published in two parts as a part of the EPA's Ecological Research Series, presents an assessment and review of: (1) the generalized cause-effect relationships between major types of forest management activities and uses and water quality parameters, such as sediment, temperature, and dissolved oxygen; (2) the magnitude of the potential problem associated with each of the major types of activities and uses; (3) management techniques available to reduce the problem; and (4) the usefulness and reliability of existing nonpoint source predictive models in planning effective forestry nonpoint source controls. It also includes an evaluation of the data base available for model development and testing.

One of the key points identified during the project was that nonpoint pollution is directly related to the time and space variability of the hydrologic cycle and existing terrain and that the relationship is site-dependent. Studies made during the course of the project also identified some major weaknesses in available predictive models.

The interagency agreement with the U.S. Forest Service also resulted in the development of a methodology for evaluating alternative erosion control strategies for silvicultural activities. As part of the study, an assessment was made of the erosion potential associated with common silvicultural activities on a nationwide basis. The project report, entitled *Silvicultural Activities and Non-Point Pollution Abatement: A Cost-Effectiveness Analysis Procedure,*[28] assesses the erosion potential of common silvicultural activities and provides a method of identifying costs and effectiveness of alternative erosion control practices.

To use this or similar cost evaluation procedures for water quality management, one must be able to relate man-induced accelerated soil erosion on the land to defined water quality goals for the receiving waters. One must also know the purpose of the activity or use, the appropriate practices for the conditions, activities and uses involved, and the local dollar costs for implementing those practices.

A private research consulting firm, Development Planning and Research Associates, conducted a study for EPA to determine and assess those current and emerging trends in U.S. silviculture and agriculture that will have the most significant environmental implications in 1985 and in 2010. Individual assessments were conducted for silviculture and harvest management, range and pasture management, livestock production, and irrigated and nonirrigated crop production. The most significant environmentally related trends were rated and rank-ordered in an evaluation workshop, comprising a panel of experts representing the Federal government, private industry, and academia. These experts assessed each trend and its environmental implications at both the regional and national levels. Each subtrend was then rated according to its extensiveness and the intensiveness of environmental effect for 1976 and 2010.

Table 16. Major Environmentally Related Trends in Silviculture and Harvest Management

Rank	Trend
1	Access to Timber Resource
2	Site Preparation
3	Log Extraction
4	Utilization
5	Fire Control
6	Growth Enhancement
7	Stand Conversion
8	Pest Control

Source: *Upper, S.G. Environmental Implications of Trends in Agriculture and Silviculture.* U.S. Environmental Protection Agency, Athens, GA. EPA-600/3-77-121. October 1977.

The silviculture panel identified regional differences within trends and their implications. Trends and their implications were assessed on a regional basis by forest types. The top trends related to silviculture and harvest management are identified in Table 16. It shows that the most important trends relate to access to timber resource, site preparation, log extraction, timber utilization, fire control, growth enhancement, stand conversion, and pest control. This study suggests that:

- BMP's will be highly variable, as the problem varies between and within regions.
- There is still much to be learned about the significance of aesthetics and ecological effects associated with forest management operations.
- Relative to agricultural nonpoint sources, forests pose less of a pollution problem on a national scale.
- Increased wood production can be achieved in an environmentally acceptable manner, with perhaps even some net improvement in environmental quality.[29,30]

WRENS—Water Resources Evaluation, Nonpoint Sources, Silviculture

A more recent Forest Service project was aimed at development of a handbook on procedures for identifying the technical suitability of alternative control strategies for a specific site and activity. This document, commonly referred to as WRENS, addresses nonpoint

source pollution in terms of site-specific relationship to existing terrain and the hydrologic cycle. The handbook describes a procedure for identifying and assessing this relationship. It also explains how to identify technically suitable control alternatives for site-specific silvicultural activities.

The WRENS handbook should prove useful to planners and managers. Information flow charts help the program planner define the technical assessments needed. The analytical procedures, example applications, and references help guide technical consultants through the assessments. And the step-by-step procedural guides and examples of control alternatives for specific conditions help project designers and managers to identify suitable controls for the particular activity and site conditions. While the specific analytical methods presented are not the only ones, they were carefully chosen according to the capabilities of the science and state of the art.

Silvicultural activities that can be evaluated using the described procedures include timber harvesting, associated transportation systems, and cultural practices, such as site preparation and timber stand improvement. These activities can be analyzed quantitatively with respect to water temperature and inorganic sediment, including that derived from surface erosion and mass wasting. The handbook procedures also allow qualitative assessment of nutrients, dissolved oxygen and organic matter, and introduced chemicals. Underlying these analyses is an assessment of the hydrologic cycle, including possible modifications from the silvicultural activity.

The handbook is process-oriented. It leads the user to consider the kinds and magnitude of on-the-ground changes that may result from the activity or use. Those changes are then assessed in terms of how they modify soil detachment and infiltration potential, volume and concentration to surface runoff, and similar factors that affect the pollutant generating and transport processes.

The handbook also contains a section on control opportunities. Controls described in the WRENS document are related to the modifications to vegetation, soil cover, drainage patterns, and other factors that may be affected, not only by the type of activity, but also by where, when, and how it is carried out. Thus, suitable preventive and mitigative alternatives for the specific site characteristics and conditions created can be identified.

The WRENS project has revealed that, despite the considerable knowledge gained from research, many of the linkage mechanisms needed to develop a fully integrated predictive system suited to quantitative analyses are still missing. For example, documented procedures for linking soil erosion rates to instream sediment loads are still incomplete. The handbook presents theoretically sound techniques to estimate values for the major mechanisms that are missing; however, some of these techniques have not been thoroughly tested. In addition, it should be noted that the handbook covers only the technical aspects of nonpoint source water pollution control. It does not address the economic, social, and institutional considerations that also form an integral component of Best Management Practices.

Other Studies

Colorado State University is evaluating the effectiveness of buffer strips along streams as a candidate forest BMP for the control of direct surface runoff related pollutants. This project will specify the abilities of buffer strips to retain sediment and sediment-related pollutants as a function of sediment properties and buffer ties and buffer media, based on hydraulic and sediment transport theory.

The U.S. Forest Service and Colorado State University are cooperatively developing a general resource planning model for the evaluation of forest management alternatives. In the forest management phase, the U.S. Forest Service is identifying those components of forest management that must be understood and predicted in order to evaluate the environmental impact of management options. These components include timber growth, cutting systems and road layout, nutrient cycling, and site productivity. Models for predicting the influence of management alternatives on the forested watershed and habitat itself also will be developed.

In the engineering phase, Colorado State University is developing a predictive model of the watershed response to precipitation for a forested watershed for which biological/physical properties are defined (based on the forest management phase). This will be accomplished via further development and refinement of existing conceptual transport models for water, sediment, and associated pollutants (organics, nutrients, and temperature). An optimization routine (goal programming) will be developed to link the management model to the transport model to enable evaluation and determination of the best integrated management system for forestry within a watershed, taking into account environmental constraints.

At the state level, much of the recent work on forestry-related nonpoint source pollution has been initiated as part of the nation's Section 208 planning program. In Oregon and Washington, for example, state environmental regulatory agencies have been assessing their existing regulations concerning management practices and the applicability of these regulations toward meeting the Federally mandated requirement for establishing BMP's.

A demonstration project by the Washington State Department of Ecology as part of its 208 program was designed to evaluate the effectiveness of an existing regulation program as compared with development of a completely new program. This project also sought to further define the extent of existing and projected nonpoint source problems, using a combination of primary research and subjective assessments.

Dr. George W. Brown of Oregon State University, who chairs the Forest Practices Act Technical Work Group, conducted an informal survey of the recent and ongoing studies of silviculture's impact on water quality in the Pacific Northwest. Results of his survey, as shown in Table 17, show about $2.3 million being spent on studies to be completed over the next 3 to 5 years.

Most of this research is Federally financed. The largest individual budgets are for Forest Service Experiment Stations, which also provide additional grant support to universities. Other monies come from the Office of Water Resources Technology (OWRT) or from EPA through state agencies in Idaho or Washington as part of their 208 effort.

Sedimentation is the primary pollutant being studied. Of the 52 projects listed, 35 deal specifically with erosion, sedimentation, and the impact on aquatic habitat. The predominance of interest in sediment results from the complexity of the process, the number of sources available, and wide variation in processes within the region.

Detailed descriptions of the studies by the program leaders makes additional generalization possible. Most of the studies are field investigations; i.e., the research focuses on obtaining basic data from field experiments, rather than modeling. There is a fairly common consensus that existing data is insufficient to derive meaningful models.

There has been a great deal of coordinated program planning between research organizations. This is to be expected when one organization, such as the Forest Service, carries the major share of the research load. But it is important to recognize that the universities also participate in this planning effort. Slope stability research, at Oregon State University for example, is being done jointly with the Pacific Northwest and Pacific Southwest Forest Experiment Stations.

The majority of the field research is done as watershed-level experiments. This is particularly true of the work by the Forest Service Experiment Stations and the work at the University of Washington. Watershed-level research is expensive because of needed long-term calibration periods prior to treatment, travel to remote locations, and data processing.

It is interesting to note that most of the research presently being conducted falls into two categories: predicting behavior of physical systems and predicting man's impact on the system. These two categories are essential building blocks for further research areas, such as: predicting response of the aquatic system and obtaining better decision models. Much work remains to be done to link these categories of research together.

Needed Research

Further research will be needed to develop more meaningful information on which to base regulations for improved forest management practices for water quality control. This research can be categorized into four areas:

- Predicting the behavior of natural physical systems.
- Predicting man's impact.
- Predicting the response of aquatic biota.
- Developing better decision models.

Predicting Behavior of Natural Physical Systems

The major research need in this category continues to be prediction of sediment transport in small streams. There are still no acceptable methods for determining natural or background levels of suspended sediment, bedload, or turbidity. The problem is one of coping with high variability. Unless researchers are able to overcome this problem, rational development of water quality standards, sampling methods to judge compliance, and evaluation of compliance will be extremely difficult. A second problem is to predict erosion, whether it be surface erosion in semi-arid range and forest watersheds or mass wasting in mountainous terrain. While several estimates of erosion rates have been obtained from watershed studies, there are no predictive models that relate erosion to fundamental processes. Without such models, rational, effective methods for control will be impossible to develop, as will development of hazard or risk rating techniques to guide managers.

Predicting Man's Impact

As mentioned previously, watershed studies have produced several point estimates of silvicultural impacts on water quality. But good techniques do not exist for extrapolating these estimates very far spatially or for predicting the impact of new technology or methods. Part of the problem is that the variability described is compounded by the additional variability imposed by man. But even more fundamental is the fact that most watershed studies have not been designed to yield good estimates of water quality changes. They have focused on erosion of soil and have provided estimates of soil loss in tons per acre per year, not concentration values so necessary for judging water quality impairment. As a result good predictive methods for judging silvicultural effects are still lacking.

Predicting Response of Aquatic Biota

Forest hydrologists agree that there is a major research need for better methods of predicting the response of aquatic organisms to altered water quality, especially from sediment. However, in predicting responses, difficulties result from the large array of highly variable organisms that must be evaluated in a fluctuating environment. At a 1978 EPA workshop on sediment and water quality, researchers[31] noted that "the sources,

Table 17. Summary of Present Research in the Pacific Northwest to Control Nonpoint-Source Pollution from Silviculture

Research Organization (Source of Information)	Study Topics	Total Budget ($)	Source[a]
Humboldt State University	X-ray Diffraction Techniques for Determination of Suspended Sediment Source Areas[b]	(not provided)	
	Hydrologic Properties of Three Coast Range Soils[b]	(not provided)	
	Scour and Fill of Spawning Gravels	15,000	USFS
University of Idaho (Dr. George H. Belt)	Best Management Practices for Silviculture[b]	100,000	Idaho
	Road Standards and Water Quality[b]	46,000	U. Idaho
	Influence of Topographic Characteristics on Sedimentation from Metamorphosed Granitic Soils[b]	15,000	U. Idaho
Oregon State University	Stream Protection During Harvesting[b]	90,000	OSU
	Overland Flow Following Tractor Harvesting	10,000	USFS
	Sediment Transport and Deposition in Small Streams[b]	150,000	OWRT & Weyerhaeuser
	Dissolved Oxygen Exchange in Turbulent Streams[b]	30,000	OSU/OWRT
	Forest Roads and Slope Stability	20,000	OSU
Pacific Northwest Forest and Range Experiment Station, Corvallis, OR (Dr. Logan Norris)	Streamflow Characteristics as Influenced by Weather and Land Management	50,000	
	Stream Sedimentation in Small Watersheds as Influenced by Natural Events	30,000	
	Stream Water Quality (Natural Chemicals)	75,000	
	Plant Succession on Harvested Areas	5,000	
	Subsurface Hydrology Effects on Slope Stability	55,000	
	Soil Mantle Creep	85,000	
	Role of Plant Roots in Maintaining Soil Strength	20,000	
	Relation Between Mass Soil Movements, Land Management Practices, and Intense Storms	20,000	
	Movement, Persistence, and Fate of Herbicides in the Forest	105,000	
	Behavior of TCDD in the Forest and Aquatic Environments	25,000	
	Entry of Fertilizer to Forest Streams	30,000	
	Persistence of DDT in Eastern Oregon and Washington	20,000	
	Behavior and Impact of Fire Retardant Chemicals in Forest Environments	20,000	
	Role of Streamside Vegetation in Maintenance of Anadromous Fish Habitat	75,000	
	Role of Intermittent Streams in Anadromous Fish Production	30,000	
	Impact of Grazing Systems on Anadromous Fish Habitat	70,000	
	Role of Large Debris and Effects of its Removal on Fish Habitat	20,000	
	Factors Affecting Stream Carrying Capacity for Fish	15,000	
Pacific Northwest Forest and Range Experiment Station, Wenatchee, WA (Dr. Arthur R. Tiedemann)	Effects of Deforestation by Tussock Moth and Salvage Logging on Streamflow and Quality	40,000	
	Effects of Harvesting Grand-fir on Soil and Streams	20,000/yr	
	Harvesting and Nonpoint-Source Pollution	30,000/yr	
	Effects of Sheep Grazing on Water Quality and Streams	15,000	
	Effects of Fire and Fertilization on Stream Water Chemistry	40,000	
	Effects in Recreation on Microbial Concentrations in Streams and Lakes	36,000	
	Effects of High Elevation Livestock Grazing on Microbial Concentrations	35,000	
Pacific Southwest Forest and Range Experiment Station, Arcata, CA (Dr. Raymond M. Rice)	Rehabilitating Landslide Scars	6,500	
	Timber Harvest and Dissolved Organics	13,000	
	Channel Morphology and Sediment Transport	90,000	
	Large Organic Material and Fish Habitat	13,000	
	Clearcutting and Slope Stability	125,000	
	Logging and Erosion	46,000	
	Roads and Erosion	14,000	
	Clearcutting and Subsurface Hydrology	80,000	
	Timber Harvesting and Flood Peaks	13,000	
	Stream Sampling Methodology	33,000	

Table 17. Summary of Present Research in the Pacific Northwest to Control Nonpoint-Source Pollution from Silviculture—Continued

Research Organization (Source of Information)	Study Topics	Total Budget ($)	Source[a]
University of Washington (Dr. David D. Wooldridge)	Effects of Clearcutting on Dissolved Nutrients in the Olympics[b]	23,000	USFS
	Effects of Clearcutting in the Olympics on Streamflow and Water Quality[b]	290,000	DNR, OWRT
	Effects of Newly Constructed Forest Roads on Water Quality	47,000	OWRT, DOE
	Log Hauling and Sediment Production[b]	26,000	DOE
	Managing Buffer Strips[b]	61,000	DOE
Washington State University (Dr. Donald R. Satterlund)	Plant Indicators of Slope Stability[b]	25,000	WSU

[a]Source of funds shown for University research projects only.

[b]Project lasts for more than one year; budgets indicate total funds allocated.

transport, and relationships of sediment with biological populations will require substantial investigation before final workable criteria can be implemented. The role of sediment in aquatic ecology is highly variable and the literature is deficient in attempts at synthesis and in crossing disciplines."

Better Decision Models

Research is necessary to supply resource managers with the information needed to make better decisions and to predict the consequences of their actions. Planners must be able to compare relative consequences of alternative silvicultural practices and policy makers need to be able to assess the costs of altering silvicultural practices and the benefits to water quality.

Research programs should be structured to enable decision makers to predict the interaction between decisions in various resource areas. Multidisciplined research must seek to define the linkages between resources and how these are altered through management decisions.

Much of the existing information about the impact of silviculture on water quality comes from watershed experiments, where results were measured in streamflow or sediment at the outlet. The factors producing the observed change usually are not quantified, leaving researchers to make some general inferences about cause and effect. Research must now take the next step: integrated, process-level studies of system function. For example, instead of measuring sediment concentrations at the outlet of a small watershed after clearcutting, sediment production will be defined as a function of soil disturbance, soil characteristics, terrain, and climatic variables. The transport and deposition of sediment in the stream channel will be defined as a function of the hydraulic factors involved. These conditions then will be related to the variables that influence aquatic organisms. From such activities, research can hope to predict response to another silvicultural operation in another watershed. This type of experimentation is illustrated by the study conducted by the U.S. Forest Service and Oregon State University on the Andrews Experimental Forest.

Once general relationships are developed from process-watershed studies, these relationships can be used to test hypotheses on a large scale. No other technique will do the job as well. Finally, the research must include the full range of physical, biological, and economic criteria by which decisions are judged.

Chapter 11

Forest Chemicals

Several groups of chemicals used in forest management can potentially affect water quality. These biologically active chemicals fall into four broad categories: fertilizers, herbicides, insecticides, and rodenticides. These materials are used to (1) enhance productivity, (2) focus the productive effort in desirable species, and (3) protect the desirable species from consumption; however, their use must be managed to prevent them from inadvertently harming the aquatic ecosystem.

Chemicals and Use Patterns

The variations in patterns of usage and dosage of major classes of chemicals used in forest management affect the likelihood of encountering pollution problems. Their biological impact in water is determined by the range of biological activity and inherent chronic and acute toxicities.

Fertilizers generally are very low in toxicity. The forms used in forests are all found in nature; the baseline levels in soils are usually much larger than the amounts applied. Fertilizer poses a potential pollution problem only because the materials are soluble at the time of application, leading to a brief period during which nutrients may move into water. The likelihood of contamination actually taking place is tied to deposition directly in open water or to the occurrence of high-intensity rainfall immediately after application. When contamination does occur, it poses no special water quality problems unless the water is trapped in an impoundment where algal bloom can result from an increase in nutrient concentration over an extended period.

Fertilizers are applied at high rates but at low frequency and in widely dispersed locations. No large-scale contamination of river systems has been encountered from fertilization. Forest fertilization is also done in established stands, where nutrients are utilized by vegetation shortly after application and are not lost from the forest system. There is no evidence that application of nitrogen fertilizers has ever led to water concentrations of nitrate approaching the 10 ppm (nitrogen equivalent) water standard set by EPA. As a result, there appears to be no special reason for being concerned about fertilization nor any special reason for modifying existing fertilization methods.

Herbicides are much more widely used than fertilizers in forests. These chemicals were quite specific in their effects on plants, and some of the most widely used materials in forests are registered for use in aquatic weed control at much higher concentrations than are encountered in forest watersheds.

Silvicultural herbicides usually are applied by helicopter in small units no more than once or twice in the development of a timber crop. Roughly 0.2 percent of the commercial forest land in the United States is treated in any given year.

Aerial applications of herbicides and their effects on water quality have been studied extensively. At no time in studies of silvicultural use of herbicides has water contamination reached concentrations known to affect the most sensitive aquatic plants or fauna. The only contamination known to be potentially harmful is that of picloram when it enters water upstream from irrigated potatoes or tobacco, and thus far, no damage to crops has been recorded as the result of water contamination. Despite widespread publicity, 2,4,5-T and silvex do not pose a special problem, even though they contain traces of TCDD (2,3,7,8-tetrachlorodibenzo-p-dioxin). These materials have been the subject of very sophisticated toxicology research, and the technological base for their continued use is stronger than that of any other pesticide.

Insecticides and rodenticides are of special interest because of their ability to injure animals at low dosages. For rodenticides, the amounts are so small and the applications so confined to baits and burrows that there is very little concerns for water quality. Insecticides, conversely, are applied to large areas in a diffuse pattern. The chance for incidental contamination of waterways is, therefore, greater than for other types of chemical applications. Moreover, the spectra of activity of insecticides indicates that for most materials, very low levels of contamination in water may result in biological impact. The persistent organochlorine compounds have the greatest potential for long-term effects.

Insecticides are subject to strict administrative control. Most aerial application projects are cooperatively scheduled over areas large enough to bear the overhead costs of monitoring and careful supervision. Despite this, most of the insecticides in use are potentially seriously harmful to fish or aquatic insect populations if inadvertently applied directly to open water or if spilled directly into a stream in significant quantities.

In summary, there is abundant evidence that aerial application of insecticides rates the highest priority for water pollution control in the use of silvicultural chemicals. Among these, the organochlorine compounds warrant special consideration to keep them from entering waterways.

Water Quality Targets

The presence of trace contamination of a chemical in streamwater does not imply that harm will result. Aerial application of any chemical normally results in minute quantities appearing in water for a matter of hours, or perhaps a few days. The alternatives to such applications, however, often have impacts on water quality that last for much longer periods, in the form of siltation, large dumps, or organic litter into stream channels, and so forth. Some of these impacts have serious implications for water users as well as aquatic fauna. It is imperative, therefore, that rules be established for safe use of chemicals. Safety is ensured by preventing biologically significant amounts of chemicals from entering water. Cleanup is clearly impractical.

The degree of tolerance by known species of aquatic organisms or water users to concentrations of chemicals in water must be known before rules governing the safe use of chemicals can be determined. Secondly, operating guidelines must ensure that water quality standards are not violated while land management goals are being met.

The toxic principles of chemical action determine the approach taken in setting limits on water concentration. Some chemicals are acutely toxic, meaning that they produce symptoms quickly or not at all. Some are chronically toxic, meaning that symptoms are likely to be delayed until deposits are accumulated, or until some metabolic function has been decreased causing detectable changes to occur. In general, the persistent compounds, especially the fat-soluble organochlorine insecticides, are the most likely to be chronically toxic. Virtually all of the herbicides and organophosphorus insecticides are in the acutely toxic category. These chemicals are usually eliminated quickly and non-lethal effects are transient. The principal concern for the acutely toxic materials is short-term evidence of lethal or severe intoxication, whereas chronically toxic materials must be evaluated over much longer periods and must be studied for signs of accumulation through food chains. Food chain magnification appears to be largely a function of fat solubility and is not a problem for pesticides other than organochlorine insecticides presently registered for use in forests.

Chemicals also can be classed according to their degrees of toxicity. Acutely toxic does not imply a high degree of toxicity, but merely that toxic symptoms show up quickly, if at all. Degree of toxicity is an inherent property of a compound once it has entered into a metabolic system. Acutely toxic materials are evaluated according to acute oral feeding or exposure levels that produce some measurable symptom in a population of test organisms. Typical determinations for rodents are lethality tests, in which a dosage that kills half the animals is known as the LD_{50} (lethal dose for 50 percent of a population). Typical determinations for fish is exposure to water having various concentrations of toxicant at various life stages. A typical expression of toxicity is LC_{50} (lethal concentration for 50 percent of a population).

Test data for most of the silvicultural chemicals is sufficient to determine at which levels of water concentration one can anticipate harmful effects on aquatic insects, fish, plants, and on animals using the water for drinking. Available data also shows at which point chemicals are likely to affect irrigated crops, either by directly affecting the crop, as with a herbicide, or by depositing an illegal residue.

All tests contain an uncertainty factor determined by random variation within test organisms. There is also uncertainty resulting from using one species of test organism to draw inferences about responses of others. Test data for many species demonstrate the degree of variation among species and show which groups are the most sensitive. Having an array of data decreases the likelihood of overlooking potential effects on any major group and virtually eliminates the likelihood of human or fish sensitivity remaining undetected. Levels of exposure where no effect occurs can be ascertained with adequate precision with these methods, especially for the acutely toxic substances.

Maximum concentrations for all silvicultural chemicals other than dinoseb were established for three classes of streams and for irrigation or potable use. These target maxima were based on a substantial margin of safety below the lowest concentration known to affect any organism likely to be exposed. Data for insects, fish, birds, and mammals were considered. Target water quality standards were given safety factors that provide for maximum exposures 10 to 1,000 times lower than the lowest concentrations known to have caused injury to fauna. The safety margin provides much larger factors for chronically toxic and persistent chemicals than for acutely toxic and quickly degraded materials.

Table 18 lists the recommended target standards for silvicultural chemicals. It provides for a graduation in allowable concentration downward with increasing size of stream and discriminates between potable standards, which provide for the safety of all aquatic organisms, and irrigation standards, which take into

Table 18. Recommended Concentration Maxima for Silvicultural Chemicals by Stream Class and User Group. Potable Waters Include Safety Factors for Wildlife and Aquatic Organisms as Well as Humans.

Class	Chemical	Most Sensitive Test Species Affected	Test Basis & Concentration	≤10 cfs		Criteria, ppm 24-hr Mean Stream Class & User 10 cfs—Navigable		Navigable	
				Potable	Irrig.	Potable	Irrig.	Potable	Irrig.
Fertilizer	Nitrate	Man	No effect, 10 mg/l	10[a]	10[a]	10[a]	10[a]	10[a]	10[a]
	Phosphate	Algae	Growth response var.	inadequate basis for recommendation					
Herbicide	Amitrole	Daphnia	LC_{50} 48 hr, 3 mg/l	0.15	0.1	0.03	0.01	0.015	0.01
	Ammonium ethyl Carbamoyl Phosphonate	Bluegill	LC_{50} 48 hr, 670 mg/l	5	5	1	1	0.5	0.5
	Arsenicals (Organic)	Man	No effect, 0.12 mg/l	0.1	0.1[a]	0.05[a]	0.1[a]	0.05[a]	0.1[a]
	Dalapon	Daphnia	LC_{50} 48 hr, 11.0 mg/l	0.5	0.1	0.1	0.02	0.10	0.02
	Dicamba	Bluegill	LC_{50} 96 hr, 23.0 mg/l	0.2	0.004	0.05	0.002	0.01	0.001
	Dinoseb			inadequate data					
	Picloram	Bass	LC_{50} 48 hr, 19.7 mg/l	0.5	0.001	0.05	0.0005	0.005	0.0001
	Silvex[b]	Chinook salmon	LC_{50} 48 hr, 1.2 mg/l	0.06	0.02	0.03	0.02	0.01[a]	0.01[a]
	Triazines	Daphnia	LC_{50} 48 hr, 1.0 mg/l	0.05	0.05	0.03	0.03	0.01	0.01
	2,4-D[b]	Bluegill	LC_{50} 48 hr, 1.0 mg/l	0.05	0.05	0.05	0.02	0.01	0.005
	2,4,5-T[b]	Bluegill	LC_{50} 48 hr, 1.4 mg/l	0.06	0.02	0.03	0.02	0.01	0.01
	TCDD	Coho salmon	No effect 96 hr, 0.000000056 mg/l	0.000000006 for all water					
Insecticide	Carbaryl	Stonefly	LC_{50} 48 hr, 0.0048 mg/l	0.001	0.001	0.0005	0.0005	0.0002	0.0002
	Diazinon	Daphnia	LC_{50} 49 hr, 0.0009 mg/l	0.0001	0.0001	0.00005	0.00005	0.00001	0.00001
	Disulfoton	Stonefly	LC_{50} 48 hr, 0.005 mg/l	0.001	0.001	0.00025	0.00025	0.00024	0.00025
	Endosulfan	Rainbow trout	LC_{50} 96 hr, 0.0003 mg/l	0.00003	0.00003	0.00001	0.00001	0.000003	0.000003
	Endrin	Coho salmon	LC_{50} 96 hr, 0.0005 mg/l	0.00005	0.00005	0.00001[a]	0.00001[a]	0.000005	0.000005
	Fenitrothion	Atlantic salmon	Behavior test 1 mg/l	0.025	0.025	0.01	0.01	0.005	0.005
	Guthion	Stonefly	LC_{50} 96 hr, 0.0015 mg/l	0.0003	0.0003	0.0002	0.0002	0.00007	0.00007
	Lindane	Brown trout	LC_{50} 48 hr, 0.002 mg/l	0.0001	0.0001	0.00005	0.00005	0.00001[a]	0.00001[a]
	Malathion	Daphnia	LC_{50} 96 hr, 0.0018 mg/l	0.0005	0.0005	0.0002[a]	0.0002[a]	0.0001	0.0001
	Phosphamidon	Daphnia	LC_{50} 48 hr, 0.0088 mg/l	0.0005	0.0005	0.0005	0.0005	0.0002	0.0002
	Trichlorfon	Stonefly	LC_{50} 96 hr,	0.002	0.002	0.0005	0.0005	0.00005	0.00005

[a]As listed in QCW.

[b]The phenoxy herbicides may occur in water as esters or other forms. The given criteria for potable water may be increased by a factor of 10 for forms other than esters. Criteria for irrigation use are for total phenoxy herbicide.

account the special sensitivity of certain crops to some herbicides. The rationale for decreasing levels with increasing size of stream is that concentration peaks move more slowly downstream in large streams than in small creeks, and more total exposure occurs in larger watercourses having a specified maximum observed concentration.

It is noteworthy that insecticides, as a group, have much lower tolerance limits than herbicides in potable water. The differences between these groups are much greater than the relative differences in nominal application rates. For this reason more attention must be given to application methods for insecticide work than for herbicide.

Chemical Behavior in Forest Applications

Water contamination can result if chemicals are applied directly to water or if runoff later carries them to streams. For those chemicals with post-treatment mobility, wide buffer zones help provide for maximum tieup in soils and organic matter prior to runoff entry into streams. For those chemicals that do not move readily, and this includes nearly all pesticides, the critical factor is in preventing direct application to water at levels exceeding the accepted criteria.

The limited mobility of most forest chemicals is attributable to their tendency to adsorb to organic material and soil colloids. Most forest soils have relatively high cation exchange capacities and low base saturations. This opportunity to fix pesticides in-situ is substantially greater than actual amounts applied. As a result, most chemicals never penetrate forest soils substantially below the duff layer. Forest soils normally have high infiltration rates, so surface runoff of chemicals in solution is rare. In short, little migration occurs in solution, either through soil or over it.

Disturbed soils are far less stable than those without recent history of machine activity. Scarified or tilled soils subjected to intense rainfall are capable of losing many tons of silt per acre in a single storm. When such soils are treated with a chemical, the adsorbed materials will move in association with the silt. The degree to which adsorbed chemicals affect stream life is related to the quantity reaching the stream, decreased by the tendency for the material to remain attached to soil. Indirect contamination of this type is more difficult to evaluate than direct contamination, because the silt tends to form deposits that continue to release small quantities of contaminant as desorption occurs. In particular, this process is especially critical when the chemicals are absorbed and retained by stream biota over an extended period. The persistent organochlorine compounds, and endosulfan used on Christmas trees in particular, warrant close attention in this situation. Silt mobility also is a consideration in the evaluation of nonchemical alternatives for vegetation control.

Direct application to open water accounts for most stream contamination. Accuracy of aircraft guidance and technology of nozzles and solvent systems are the most useful controls over direct placement of chemicals in water. This form of contamination is a brief concentration spike that cannot provide chronic exposure. If the peak is not harmful, no effects occur. Thus, elimination of harmful peaks is the first line of water protection.

An aircraft releases chemicals through nozzle systems that break the spray into droplets of various sizes. Applications requiring heavy coverage and precise targeting, such as herbicides, are delivered in relatively high volumes of liquid, through large-orifice nozzles that emit large drops. Conversely, insecticides are generally applied in general treatments in which very fine sprays are delivered over large areas. Very low volumes of total liquid per acre are required for effectiveness in large projects, yet a deficiency of droplets per square inch of foliage can allow too many insects to survive. The droplet size therefore is reduced to increase the density of droplets per unit of foliage and to increase the uniformity of coverage between aircraft swaths. Unfortunately, the very technology that contributes to effective insect control also enhances the difficulty of precise targeting of the spray. Thus, effective insecticide applications near streams are likely to deposit significant amounts of material in the water. Except for certain of the most selective of the insecticides and biological agents, such deposits are likely to have some effects on aquatic insects or fish, depending on the specific chemical.

Herbicides are more amenable to technical spray modification without loss of effectiveness. Spray nozzle configurations that increase uniformity of droplet size and decrease the proportion of fine droplets with high drift potential are available. Spray thickeners, emulsification agents, and foams may be used to decrease fine droplet movement away from the target zone. The use of helicopters, rather than fixed-wing aircraft, also improves precision.

For many species of vegetation requiring control, there are several herbicides available. Some herbicides usually have lower impact on aquatic systems than others, and unusually sensitive areas may be treated with some of them by helicopter without having direct impact on water quality. There are some opportunities for substitution of insecticides, as well, but margins of selectivity are not as great.

Herbicides applied with conventional cone-nozzle systems delivering 10 gallons (0.038 m^3) of water per acre (4,046 m^2) usually will show a rather precise swath boundary. In the absence of wind drift, deposits 50 ft (15.24 m) from the edge of a spray project will approximate 5 percent of the nominal application rate, or less. Insecticides, on the other hand, are applied from greater distances above the canopy of vegetation in smaller droplets, their swaths are wider, and swath tails extend further from the target boundary.

The width of a chemically free buffer zone along a stream is often expressed in terms of swath widths

of the aircraft. The effective swath width (ESW) of a spray aircraft is the maximum distance permissible between successive swaths without having a measurable decrease in dosage between swaths. The actual swath width is much wider, in view of the movement of fine droplets to distances of several boom lengths either side of the aircraft. In practice, every swath consists of a principal application centered on the flight line, plus minor deposits from adjacent swath tails. The elimination of such tails improves ability to avoid minor deposits in water.

Guidelines for Protection of Water Quality

Table 19 provides a list of forest management practices involving the application of chemicals and outlines the rules for buffer strip treatment and monitoring to meet the water quality and productivity goals. Methods used to reduce impact of chemicals (Priority I) include designation of buffer zones of widths in accordance with the potential hazard posed by the chemical. The rationale behind recommendations for buffer-strip widths is based on the earlier described 20-fold decrease of contamination with each herbicide swath width away from the stream and five-fold decrease per swath of low-volume insecticides with winds less than 5 mph (8.04 kmph). Based on experience with various pesticides, the proposed criteria for water concentrations will be met with a margin of safety when registered rates of application are applied as recommended. In those exceptions where buffer strips are defined in terms of absolute width, the problem being addressed is the physical movement overland or through the soil in subsurface flow, a group of processes not affected by application technology.

To achieve the second priority, meeting forest production goals without compromising water quality, identification of practices that have adverse impacts near water and substitution of less harmful practices is emphasized. Exceptional conditions under which untreated buffer zones are recommended are identified so that unnecessary loss of productivity can be avoided.

Monitoring will be needed to insure that the recommendations are (1) being observed and (2) effective in maintaining water quality. Monitoring for validation of practices will be the responsibility of state and Federal water resources agencies, and operational quality control will be the responsibility of the operator. Monitoring of insecticides by users, in particular, will be necessary on a limited scale to provide a record of the consequences of chemical activity at the point of maximum potential trouble. The intensity of monitoring is specified in Table 19.

In conclusion, biologically important direct impacts from herbicides, rodenticides, and fertilizers will not occur when used as prescribed. Virtually all commercial forest lands adjacent to streams may be managed in ways that include the use of such chemicals without impairing water quality. Insecticides also may be used, but substantial buffer zones and greater operational quality control and monitoring are in order. By following these rules, management goals may be achieved without major extra cost and without resorting to nonchemical tools having adverse impacts.

Table 19. Guidelines for Applying Chemicals by Aircraft, and Water Monitoring in Silvicultural Practices

Practice	Chemical Used	Minimum Distance Between Nearest Water and Center Line of Nearest Swath	Treatment of Buffer	Suggested Location and Frequency of Water Sampling
Fertilization	Urea	¾ of an effective swath width (ESW).	Apply by ground rig.	Composite, Day 1, at potable user site, if within 1 mile downstream from project.
	Phosphorus	¾ ESW[a] Exceptions: upstream from lake or impoundment.	Apply by ground rig.	None
Forest Site Preparation	Amitrole	½ ESW[a] Exceptions: within a mile of potable users, 50-foot buffer.	(1) Apply by ground rig. (2) Apply substitute chemical. (3) Plant buffer zone with tolerant tree species.	Composite, Days 1 & 2, at potable user site if within 1 mile downstream.
	Ammonium ethyl Carbomyl phosphonate	½ ESW[a]	Can be treated.	Composite, Day 1 at potable user site if within 1 mile of project downstream.
	Atrazine	½ ESW[a] Exceptions: scarred areas, 50 feet.	Do not disturb soil within buffer zone.	None
	Dalapon	½ ESW	Do not disturb soil within 50 feet of creek.	None

Table 19. Guidelines for Applying Chemicals by Aircraft, and Water Monitoring in Silvicultural Practices—Continued

Practice	Chemical Used	Minimum Distance Between Nearest Water and Center Line of Nearest Swath	Treatment of Buffer	Suggested Location and Frequency of Water Sampling
	Phenoxys	½ ESW	Can be treated.	Composite, Day 1, at intake if potable user within 1 mile of project downstream.
	Picloram	100 feet (200 feet when applied during period of rainfall surplus).	Can be treated with substitute chemical within prescribed limits.	Composite, weekly at irrigation user if within 5 miles of project, and crops include potatoes, tobacco or legumes. Sample after spraying, again in sequence after effective rainfall.
Forest Insect Control: Biological	Bacillus thuringiensis	None[a]	Can be treated.	None
	Nuclear polyhedrosis	None[a]	Can be treated.	None
Chemical	Carbaryl	1 ESW[a] or 100 feet, whichever is greater.	May treat with biological agent.	Composite each day of spraying immediately downstream from project and above potable user, and 2 days after. Sample at water intake, if within 2 miles of project. Filter samples.
	Diazinon	Same as Carbaryl.	Same as Carbaryl.	Same as Carbaryl.
	Disulfoton	Same as Carbaryl.	Same as Carbaryl.	Same as Carbaryl.
	Endosulfan	4 ESW[a] or 300 feet, whichever is greater.	May treat with carbaryl diazinon, fenitrothion or phosphamidon to 1 ESW from water.	Sample as with organophosphorus insecticides, but sample also after each heavy rain for next month.
	Fenitrothion	1 ESW[a]	Same as Carbaryl.	Same as Carbaryl.
	Guthion	3 ESW[a] or 200 feet, whichever is greater.	Same as Carbaryl.	Same as Carbaryl.
	Malathion	3 ESW[a] or 200 feet, whichever is greater.	Same as Carbaryl.	Same as Carbaryl.
	Phosphamidon	1 ESW[a] or 100 feet, whichever is greater.	Same as Carbaryl.	Same as Carbaryl.
	Trichlorfon	1 ESW[a] or 100 feet, whichever is greater.	Same as Carbaryl.	Same as Carbaryl.
Roden Control(Seeding): Chemical	Endrin	¾ ESW	Can be treated by hand.	None

[a]For definition and discussion of ESW see page 55. Designation of "None" or ½ ESW under Buffer Strip Width implies only that buffer strip width is at the discretion of the operator and that direct impact on water quality is not at issue. Even without a buffer strip, the aircraft should never be operated within a half-ESW of streams that are likely to have fish in them at time of chemical application. For those insecticides requiring one or more effective swath widths, the proposed buffers are for helicopters with droplet size of 200 μMMD. If droplets are smaller or large fixed-wing aircraft are used, buffers should be 200 feet (61 m) plus the given swath numbers. Helicopters may be used in conjunction with large aircraft.

Sediment Contributions from Southern Forest Management Practices

Introduction

By the year 2000 the demand for wood from the 12 southern states is expected to double. Southern forests, which now produce almost one-half of the nation's wood, will need to produce 70 percent more softwood and 40 percent more hardwood. This expected increase in production will call for the conversion of 20 million acres (80 Gm^2) of low-quality upland hardwoods to pine, the reforestation of 10 million acres (40 Gm^2) of unstocked or poorly stocked forest land, and the planting or natural regeneration of lands being harvested. To reach these goals, intensive management must be implemented on more southern forest land. Concurrently, the water resource must be protected or improved. Thus, the primary challenge facing southern wood producers is to increase production at competitive costs while minimizing nonpoint source pollution—particularly sediment contributions.

Baseline Levels and Water Quality Standards

The Clean Water Act requires that states review and revise water quality standards and then develop water management plans. To establish a baseline from which to set these standards, the quality (natural background level) of water flowing from undisturbed forest lands and its natural variability must be determined. However, the National Commission on Water Quality (1976) has been unable to describe this natural water quality; i.e., water quality at the time of the European colonization of the continent. Thus, appropriate natural background levels for water quality are those produced by present-day, not-recently-disturbed forest lands.

Past research has indicated a concentration of 0.0066 tons/acre-in (about 58 mg/l or ppm) as the average annual base rate for sediment in stormflows from small, undisturbed catchments of southern pine. Average annual sediment concentration appeared an adequate expression of the natural background level because concentrations were not correlated with individual stormflow volumes or with annual or average annual water yields.[32] However, concentrations for individual events, due to natural variations, may be higher by a factor of 10 or more. The higher rates result primarily from the occasional flushing of inorganic sediment and organic debris accumulated in channel networks.

Data collected for 88 years from 10 catchments supporting loblolly pine planted to control erosion and mature shortleaf pine-hardwoods show that sediment concentrations for the mature pine-hardwoods ($n = 30$) did not differ statistically from those for the pine plantations ($n = 58$). The overall mean for both types was 0.007 tons/acre-in (61.51 mg/l). The fact that pine established on severely eroding lands can, in less than 20 years, reduce sediment concentrations to levels of mature pine-hardwood types suggests a high recovery potential after the initial rotation. It seems possible to predict a prompt and complete recovery even after severe disturbances.

To provide an interim reference, the figure 0.007 tons/acre-inch can be considered as the natural background level for undisturbed, well-stocked southern pine types in the Coastal Plain. The standard error of this mean is $\pm$ 0.0008 tons/acre-in (7 mg/l). Because of the rough terrain, highly erosive soils, and past abuse of the catchments cited, 0.007 tons/acre-in may be slightly higher than the mean for the southern Coastal Plain pinery; however, this rate falls within the limits of values for a wide range of undisturbed eastern forest types.[33,34,35,36]

To further define natural background levels, Stanley J. Ursic of the Southern Forest Experiment Station compiled 22 years of data for each of two other forest land cover types: (1) abandoned lands with a dense cover of native grass representing lands requiring reforestation to pine; and (2) poorly stocked upland hardwood stands typical of those being converted to pine. Basal area per acre of the hardwood stands averaged 52 ft^2 (4.83 m^2), of which 23 ft^2 (2.140 m^2) were cull. Average annual sediment concentrations between the two types did not differ statistically. However, the average concentration for these covers differed significantly from that of the pine types and represented a discrete population of erosion potential. The annual sediment concentration for the unstocked lands and depleted hardwoods averaged 0.026 ton/acre-in (228.5 mg/l), almost four times the rate of the pine covers.

Results of studies at the Southern Forest Experiment Station are confirming differences in sediment concentrations among forest land covers. Results forecast

an improvement in water quality following conversion of low-quality upland hardwoods to pine. Compared to 5-year pretreatment means, average annual sediment concentrations were reduced an average of 64 percent during the fourth through the seventh years after hardwoods on two of the small catchments cited were deadened with chemicals and underplanted with pine (Ursic, unpublished data). The long-term improvement of water quality demonstrated in this study[37] indicates that initial impairment is only temporary and will be more than compensated for over a rotation.

Channel Contributions

Since there is little, if any, overland flow from well-stocked forests, most of the sediment yield results from channel erosion. Because of wide variations in channel stability and conditions, sediment contributions from channels should be evaluated apart from those caused by forestry activities and should be considered when developing water quality standards to prevent placing needless restrictions on forest lands. On the upper reaches of a drainage network, sediment losses are largely a natural phenomenon, and channels in hilly terrain may drain just a fraction of an acre. But the quality of water from forested lands in the Coastal Plain progressively worsens as it continues downstream. One main factor is the degrading of silted channels and floodplains caused by previous farming. Channels occupying 1 percent of a watershed area and eroding at the rate of 0.01 in/yr (0.025 cm/yr) contribute an equivalent of 0.02 tons (18.14 kg) per watershed acre (4,046 m^2), but Coastal Plain channels often eroded at much higher rates. For example, the average annual sediment concentration from an 88-acre (356,000 m^2) Coastal Plain catchment to rehabilitate the loblolly pine was found to be 13 times as great as the suggested base rate (0.007 tons/acre-in) for small headwater areas. An additional 0.09 tons/acre-in (790.9 mg/l) was contributed by the larger sandbed channels. Sediment contributions from some Coastal Plain channels that drain several thousand acres in mixed land use may be so great as to obscure the effects of any or all forest land management practices.

Harvesting Impacts

Among harvesting options, clearcutting can have the greatest short-term impact on nonpoint source pollution. However, over the long term, total or average annual impact over a rotation may be equal or greater for a silvicultural system that includes more frequent cutting. Where temporary roads are the primary sediment source, frequent reentry could make the impact greater and the nonpoint source control costs higher.

The cutting of trees has little direct effect on water quality, since basic hydrologic processes are essentially unaltered. Any adverse impact results primarily from soil disturbances caused by removing the trees and by the rapid oxidation of the forest floor following removal of the canopy. Skidding causes the most serious disturbances, but in the South, skidding seldom disturbs more than 20 percent of clearcut area.[38] In one study, erosion was measured from 20 trails created by uphill skidding of hardwood logs on a variety of soils, slopes, and slope lengths.[39,40] During the first year, soil moved from the trails at concentrations averaging 0.124 tons/acre-in (1090 mg/l). Although soils were severely compacted, vegetation rapidly invaded the trails, and concentrations during the second year averaged 0.023 tons/acre-in (202 mg/l) (a five-fold reduction). These rates seldom apply to more than 20 percent of a clearcut area, and they represent soil movement (i.e., a relocation on slopes) and not nonpoint source pollution, which involves the delivery of particulate matter into a channel. The bulk of these deliveries can be prevented.

Similarly, rapid oxidation of the forest floor can result in localized soil movement, but in the humid subtropical areas of the South, invasion of herbaceous vegetation quickly compensates for reductions of the forest floor. In the skid trail study cited, bare soil on trails was reduced from 30 to 11 percent during the first year and to 3 percent after 2 years. The average amount of bare soil on four small catchments of loblolly pine after clearcutting the tree-length skidding similarly declined from 10 percent 1 year after logging, to 7 percent after 2 years, and to 5 percent after 3 years.

The Southern Forest Experiment Station, Forest Hydrology Laboratory, has been conducting a cooperative study on the Natchez Trace State Park and on the Pine Tree Branch Watershed (TVA) in west Tennessee. Using small catchments to obtain integrated impacts of harvesting loblolly pine plantations, researchers replicated four treatments twice at each location. Treatments consisted of clearfelling and planting with and without seeding an annual grass on disturbed areas, strip-cutting on contour to remove about three-fourths of the volume, and undisturbed pine plantations (controls).

Landings and haul roads were excluded from this study because of the small size of the catchments. Commonsense practices were applied to create disturbances that maximized on-site detention of rainfall and moving sediment. Trees were felled away from the channels and skidded tree-length, roughly on contour, to the nearest spur ridge and then to the landing. Most importantly, the channels were not disturbed. These measures were taken with little, if any, increase in logging costs, although they required working closely with the feller and skidder operator.

From the first 2 years of the study 27 sets of runoff events from the Pine Tree Branch watershed were examined. The average discharge-weighted con-

centration of sediment for the controls [0.009 tons/acre-in (79 mg/l)] was somewhat higher than the suggested base rate for pine types, partly as a result of disturbances during installation of measuring devices. An average was taken for the six harvested catchments, and this average was compared to the mean for the controls. Average sediment concentration from the harvested areas for the 27 events was about six times higher than the controls. Much of this increase was from one catchment with a deeply incised channel. The increased sediment delivery resulted from enlargement of small, subsurface, pipe-like channels that dumped sediment directly into the main channel. Average sediment concentration, excluding this anomalous catchment, was three times that of the controls. It appears that, after clearcutting pine, water quality is comparable to that cited for unstocked lands and lands occupied by low-quality hardwoods [0.026 tons/acre-in (228 mg/l)].

These particular catchments represent an extreme erosion hazard for Coastal Plain conditions. Had practices that did not consider water quality been used, sediment concentrations could have been considerably higher. However, this preliminary data indicates that southern pines in the Coastal Plain can be clearcut without serious or long-lasting impairment to water quality. Where mitigative controls are called for, sediment concentrations after harvesting can be reduced effectively by placing temporary, low-cost structures to hold sediments in the small ephemeral channels. Small brush dams, for example, effectively trap the bulk of larger particles.[41]

Although temporary and permanent road systems used to manage forested tracts have a high potential for producing sediment, this problem can be handled with current technology. Almost all serious or continuing damage is preventable.[42,43] It is a costly business, but there are no easy alternatives except to design harvesting systems requiring fewer roads.

Regeneration Impacts

Intensive mechanical site preparation, which is used when converting hardwoods to pine or preparing sites for pine regeneration, presents a serious nonpoint source problem. Site preparation practices include tree-crushing, root-raking, chopping, discing, bedding, chipping, and other techniques used singly or in combination. Some restrictions may be needed, because such practices can bare three-fourths or more of the soil. This kind of exposure and soil compaction can result in sediment-producing overland flows and in large increases in stormflow volumes. However, the magnitude and duration of the impacts of such practices have not been adequately quantified.

The Southern Forest Experiment Station Forest Hydrology Laboratory is currently measuring the impacts of several widely used site preparation practices. As expected, stormflow volumes have increased, but the effect on sediment concentrations has not been adequately defined. One study involving three methods of intensive mechanical preparation indicates that sediment yields during the first year after treatment are comparable to those considered acceptable for agricultural lands. Sediment concentrations after site preparation are expected to decline rapidly; increased water yields are expected to persist longer because of soil compaction.

In a recent study of site preparation practices in the North Carolina Piedmont, root-raking was compared with broadcast burning. Root-raking, which creates a greater nonpoint water pollution source hazard than burning, reduced the site index of loblolly pine 14 ft (4.26 m) and volumes at age 20 by 11 cords per acre (.01 m^3/m^2). The chairman of a recent workshop on site preparation concluded that the trend is toward less intensive practices and that the overriding consideration was not nonpoint source control, but rapidly escalating operational costs.[44]

Wood Preserving

Introduction

The wood-preserving industry in the United States comprises about 400 commercial treating plants, 350 of which are equipped with pressure retorts. Most of these plants are concentrated in two distinct regions. The larger region extends from East Texas to Maryland and corresponds roughly to the natural range of the southern pines, the major species utilized. The second concentration of plants is located along the Pacific Coast, where Douglas fir and western red cedar are the species of primary interest to the industry. Less than 25 percent of the plants, and a much smaller percentage of production capacity, are located outside these two regions.

Creosote in its various forms, pentachlorophenol-petroleum solutions, and various inorganic salt formulations based on copper, chromium, and arsenic are the preservatives used by the industry. All plants use at least one of the three and 80 percent employ two or more in their operations. Many plants treat with two or three preservatives and a fire retardant. Copper-8-quinolinilate and tributyl tin oxide are also used by a limited number of plants.

Stock may be treated seasoned or unseasoned. In the latter case, the wood is conditioned in the retort prior to treatment. Both Boultonizing and steaming are used for this purpose, the former process being employed principally with the West Coast species—notably Douglas fir—and the latter with the southern pines. Because of the relatively large volume of condensate generated by these operations and its high phenol content and oxygen demand, the conditioning processes account for an important part of the pollution problem in the industry.

Significant progress has been made by this industry since 1972 in installing the technology required to meet current BPT and BAT effluent guidelines. However, the level of technology that will be required to meet revised BAT discharge standards, including probable restrictions on priority pollutants, is unknown at this time. Wastewater treatment and disposal technology currently used by the wood-preserving industry are summarized here. Technology not used but which may have application to the industry or a segment thereof is also discussed.

Wastewater Characteristics

Wastewater characteristics of the wood-preserving industry are unique among wood-base industries. This uniqueness stems not so much from wastewater volume, which generally is quite small, as from the number and concentration of conventional and priority pollutants that it contains.

Among the several factors influencing both the concentration of pollutants and volume of effluent, total conditioning time, whether by steaming or Boultonizing, is the most important. Water from conditioning accounts for most of the loading of pollutants in a plant's effluent. With the exception of single-pass cooling water, conditioning water accounts for the largest volume. There is also a large volume of rainwater that falls on or in the immediate vicinity of the retorts and storage tanks (an area of about 1 acre for the average plant). Contaminated rainwater presents a treatment and disposal problem at most plants, but can be especially troublesome for plants in areas of high rainfall.

Wastewaters resulting from treatments with inorganic salt formulations are low in organic content, but contain traces of heavy metals used in the preservatives and fire retardants employed. The presence and concentration of a specific ion in wastewater from such treatments depend upon the particular formulation and the extent to which the waste is diluted by washwater and stormwater.

In addition to conventional wastewater parameters, such as oil and grease and chemical oxygen demand, EPA has identified 129 elements and compounds (see Chapter 9, Table 14) that present a real or potential health hazard because of their toxicity and actual or suspected mutagenicity, tetrogenicity, or carcinogenity. Designated priority pollutants, a number of these materials have been identified in effluents from the wood preserving industry. Except for the metals, which are associated with inorganic salt-type preservatives and fire retardants, most of the priority pollutants are constituents of creosote.

The volume of wastewater discharged from a given wood-preserving plant varies with the conditioning method used, type of preservatives, the extent to which contaminated and uncontaminated waste streams

are segregated, the volume of water that is recycled, and the volume of rainwater that falls on or in the immediate vicinity of the retorts and preservative storage tanks. Data from 18 Boulton and 41 steaming plants gave average discharge values of 6,785 and 7,375 gpd (25.6 and 27.9 m^3/d), respectively. When only western Boulton plants and closed-steaming plants were compared, the average discharge volumes were, in order, 3,425 and 3,215 gpd (13.06 and 12.2 m^3/d). Nationally, it is estimated that the average two-retort plant generates 8,000 gpd (30.3 m^3/d) of wastewater, including 4,000 gpd (15.1 m^2/d) of contaminated rainwater.

Boulton Conditioning Process

Preconditioning is accomplished in the Boulton process by heating the stock in a preservative bath under reduced pressure in the retort. The preservative serves as a heat transfer medium. Water vapor from the wood during the Boulton process passes through a condenser to an oil-water separator where low boiling fractions of the preservative are removed and returned to treatment solutions. The Boulton cycle may have a duration of 48 hours or longer for large poles and piling. The step may be accomplished either by pressure or non-pressure processes. Figure 14 shows a Boulton wood preserving plant. Steps in the process are described in the following paragraphs.

- *Water in Wood into Cylinder.* The amount of water that comes in with the wood depends upon the moisture content of the wood. Green wood of small diameter may have a moisture content in excess of 100 percent on a dry weight basis. Larger diameter wood contains heartwood, which has a moisture content of about 35 percent. The stock may be partially dry and therefore have a moisture content between 35 and 100 percent.

  Water Entering with Wood
  = 20 lb/ft^3 (320 kg/m^3) for large diameter poles [10 to 12 in (25.4 to 30.48 cm)]
  = 32 lb/ft^3 (512.6 kg/m^3) for wood with 100-percent moisture content

  From an operational standpoint, the quantity of water in the sapwood, the outer 2 in (5.08 cm) of the wood, is most important. Conditioning mainly removes water from the sapwood; little water is removed from the heartwood.
- *Preservatives to Cylinder.* The preservative is then added to the cylinder and heated with steam coils at the bottom of the cylinder. Steam condensate is returned to the boiler.
- *Vapors.* After the oil has been heated, a vacuum is drawn on the cylinder for 10 to 40 hours for Douglas fir and 6 to 12 hours for oak, depending upon the initial moisture content of the wood. The oil transfers heat to the wood and vaporizes the water. Between 4 and 20 lb/ft^3 (64 and 320 kg/m^3) of wood are removed.
- *Air and Vapors.* The vacuum pump removes mostly non-condensible gases and water vapor from the system. The quantity of water expelled is unknown.

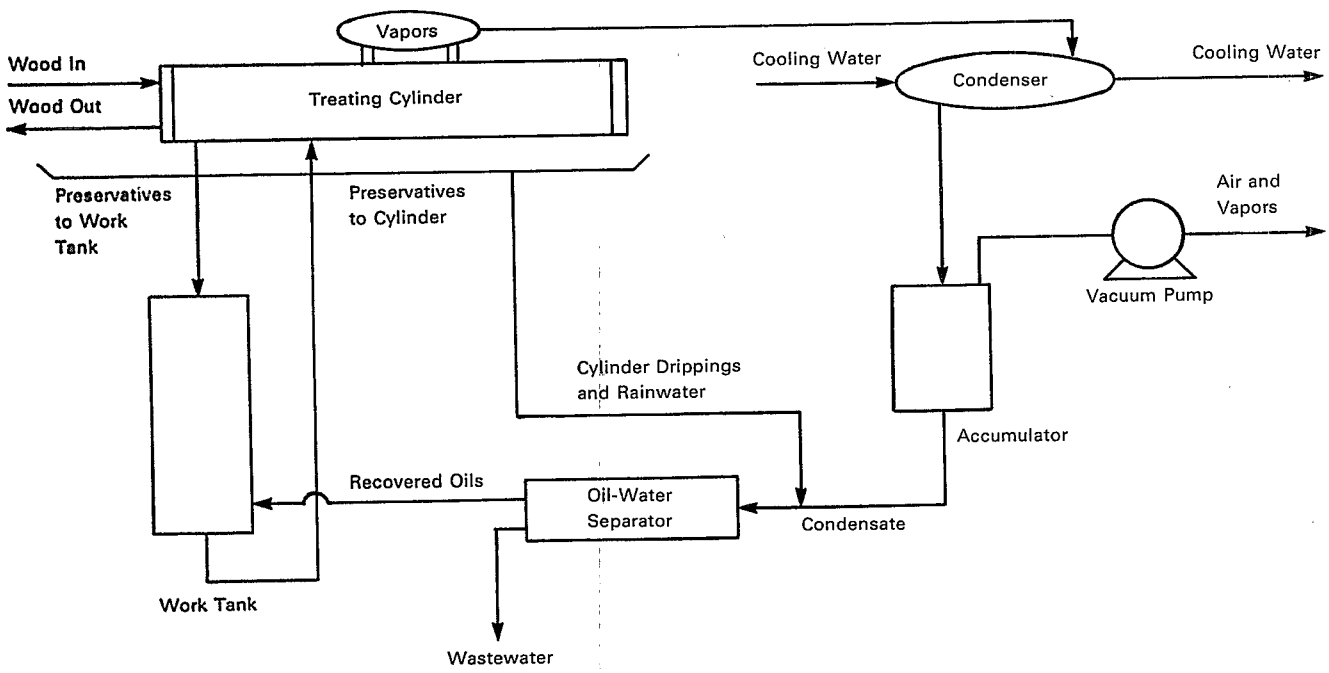

Figure 14. Diagram of a Boulton Process Wood Treating Plant.

- *Preservatives to Work Tank.* After the treatment process, the preservative is drained from the cylinder and transferred to the work tank.
- *Wood Out.* The treated wood is removed from the cylinder. The average moisture content of the stock, which is dependent upon the original moisture content of water removed as a vapor, will be around 35 percent, or about 6 to 12 lb/ft^3 (96 to 192 kg/m^3). The moisture in the sapwood will be between 2 and 4 lb/ft^3 (32 and 64 kg/m^3).
- *Cylinder Drippings and Rainwater.* Cylinder drippings and rainwater often are added to the flow from the cylinder and fed to the oil-water separator. In some plants they are fed to a separate oil-water separator to prevent cross-contamination of preservatives. Rainwater can vary between 0 and 11.3 lb/ft^3 (0 and 181 kg/m^3) for conditions of no rain to 1-in (2.54 cm) rainfall in 24 hours, and depending upon the area drained toward the treating cylinder. This flow can be evened out by sufficient rainwater holding capacity. The minimum area in which rainwater is collected includes the immediate cylinder area, the area where the wood removed from the cylinder drips extra preservatives, and the tank farm. Rainfall will produce a yearly average rainwater flow of 2 lb/ft^3 (32 kg/m^3).
- *Recovered Oils.* Oils recovered in the oil water separator are returned to the work tank.
- *Wastewater.* The quantity of wastewater produced depends upon the amount of green wood conditioned and rainfall. Wastewater generated will be between 3 and 22 lb/ft^3 (48 and 352 kg/m^3).

Current Treatment and Control Technology

With some minor exceptions, the wood preserving industry has already installed, or has available to it, the technology required to meet current effluent guidelines. The level of technology that will be needed to meet new BAT guidelines, which are presently being reviewed, and to conform to probable restrictions on priority pollutants is unknown at this time. If it exceeds that which is either currently in use or has been indicated for the industry by appropriate studies, a higher level of technology will be required. Technology currently used by the industry is summarized in the following paragraphs. This summary is followed by a review of technologies currently unused, or used by a single plant, but which may have application to the whole industry or a segment thereof.

Reduction in Volume of Wastewater

The volume of process wastewater generated by the average plant that employs steam conditioning has been reduced almost 70 percent—from 13,000 to 4,000 gpd (49.4 to 15.2 m^3/d)—since 1973. Factors that have contributed to this reduction include the following:

- Adoption of closed steaming as a replacement for open steaming.
- Replacement of barometric-type with surface-type condensers.
- Recycling of barometric cooling water.
- Predrying of a higher percentage of production than previously, thus reducing total steaming time.
- Segregation of contaminated and uncontaminated waste streams.
- Inauguration of effective plant maintenance and sanitation practices.
- Recycling of coil condensate.
- Recycling of process water.

Because cylinder condensate resulting from steam conditioning is the most important source of wastewater, the adoption of closed steaming, which permits this waste stream to be recycled, has contributed most to a reduction in total pollution loading and, at some plants, wastewater volume.[45] Predrying of stock preparatory to preservative treatment, a practice that negates the need to steam condition, has had a commensurate effect at some plants.

Installation of facilities to recycle cooling water for barometric condensers has reduced the total volume of wastewater at plants using a single-pass system to a fraction of its original volume. The practice of recycling this water, or, alternatively, installing surface-type condensers, was quickly adopted by the industry when it became evident that it was not economically feasible to treat the large volume of contaminated water generated by a single-pass, barometric-condenser system.[43]

Reuse of process water is not widely practiced in the industry. There are, however, noteworthy exceptions to this generalization. Process wastewater from salt-type treatments is so widely used as makeup water for treating solutions that the practice is now common industrywide. Of 184 plants treating with salts that were questioned in 1974, 160 indicated that they have achieved zero discharge of direct process wastewater through a combination of water conservation measures, including recycling.[46] All except three of the salt plants responding to a recent EPA questionnaire stated that they had achieved a zero discharge.

Condensate from steam coils is one of the main sources of uncontaminated water at wood-preserving plants. While previously this water was frequently allowed to become mixed with process wastewater, most plants now segregate their waste streams, thus reducing the total volume of polluted water. Many plants now recycle their coil condensate for boiler feedwater, a use for which it is admirably suited because of its purity and high BTU content.

Primary Treatment

Oil-Water Separation. Because of the deleterious effects that oil has on all subsequent steps in a treatment regime, efficient oil-water separation is basic to effective wastewater treatment. Oil, whether free or in emulsified form,

accounts for a significant part of the oxygen demand of wood-preserving effluents and, in the case of wastewater from pentachlorophenol processes, serves as a carrier for concentrations of the chemical that far exceed its solubility in oil-free water. In a real sense, control of oils is the key to wastewater management in this industry.

API-type oil-water separators are extensively used by wood-preserving plants for primary oil separation from wastewater. This process is preceded and followed at many plants by a rough oil separation and secondary oil separation, respectively. The rough oil separation occurs either in the blowdown tank or in a surge tank preceding the API separator. Secondary separation usually occurs in another API separator operated in series with the first, or it may be conducted in any vessel or lagoon where the detention time is sufficiently long to permit further separation of free oil. A few plants achieve almost complete removal of free oils by filtering the wastewater through an oil-absorbent medium. This practice may be unnecessary if the wastewater is to be chemically flocculated.

Oil content of wastewater entering the blowdown tank may range as high as 10 percent, with 1 to 5 percent the usual range. Depending upon the efficiency of rough separation, the influent to the primary separator will have a free oil content in the range of less than 200 mg/l to several thousand mg/l. Removal efficiencies of 60 to 90 percent can be achieved, but the results obtained are affected by temperature and oil content of the influent and by separator design, especially with regard to detention time. Data published by the American Petroleum Institute[47] shows that 80 percent removal of free oils is normal in the petroleum industry. Secondary separation should remove up to 90 percent of the residual free oil, depending upon the technique used.

Chemical Flocculation. Because oil-water emulsions are not broken by mechanical oil-removal procedures, chemical flocculation is required to reduce the oil content to a satisfactory level for wastewaters containing emulsions. Lime, ferric chloride, various polyelectrolytes, and clays of several types are used in the industry for this purpose. Automatic metering pumps and mixing equipment have been installed at some plants to expedite this process, which is usually carried out on a batch basis. COD reductions of 30 to 80 percent or higher are achieved—primarily as a result of oil removal. Average COD removal is about 50 percent.

Influent oil concentration varies with the efficiency of mechanical oil separation and the amount of emulsified oil. The latter variable in turn is affected by type of preservative—either pentachlorophenol in petroleum, creosote, or a creosote solution of coal tar or petroleum—conditioning method used and design of oil-transfer equipment. Pentachlorophenol preservative solutions cause more emulsion problems than creosote or its solutions, and plants that steam condition—especially those that employ open steaming—have more problems than plants that use the Boulton conditioning method. Plants that use low-pressure, high-volume oil transfer pumps have less trouble with emulsions than those that use high pressure, low-volume equipment.

Typically, influent to the flocculation equipment from a creosote process will have an oil content of less than 500 mg/l, while that from a pentachlorophenol process will have a value of 1000 mg/l or higher. For example, analyses of samples taken from the separator outfalls at 10 plants revealed average oil contents of 1470 and 365 mg/l for pentachlorophenol and creosote wastewater, respectively. The respective range of values was, in order, 540 to 2640 mg/l and 35 to 735 mg/l. Average separator effluents for three steaming plants sampled in conjunction with a recent study gave oil and grease (O & G) values of 1690 and 935 mg/l for pentachlorophenol and creosote separators, respectively.

Flocculated effluent generally has an oil content of less than 200 mg/l and frequently the value is less than 100 mg/l (Table 20). Significant reductions in pentachlorophenol content (PCP) also are achieved by flocculation. In some instances, the reduction in this parameter is such that the final value is less than the solubility of the chemical in water—about 17 mg/l at 68° F (20°C). This result is attributed to the selective adsorption of pentachlorophenol by the oil phase, which is removed during flocculation.

Table 20. Reduction in Content of Selected Wastewater Parameters Due to Flocculation Treatments

Plant No.	Before Flocculation (mg/liter)			After Flocculation (mg/liter)			% Reduction		
	O&G	COD	PCP	O&G	COD	PCP	O&G	COD	PCP
1	2,640	12,627	47.8	165	6,645	5.2	94	47	89
6	24,450	147,555	860	90	4,645	134	99+	97	84
7	735	15,695	-	245	10,515	-	67	33	-
9	270	22,915	26.7	45	20,390	9.0	83	11	66
10	3,010	15,345	-	120	2,565	-	94	84	-
14	35	1,170	5.7	20	530	2.71	43	69	53

Filtration. Many plants that flocculate their wastewater filter it through sand beds to remove the sludge. When properly conducted, this procedure is highly efficient in removing both the solids resulting from the process as well as small amounts of residual oil. The solids that accumulate on the bed are removed periodically along with the upper inch or so of sand.

A common mistake that renders a filter bed almost useless is to discharge incompletely flocculated wastewater on it. The residual oil effectively prevents percolation of the water through the bed, thus necessitating the replacement of the oil-saturated sand. This has happened frequently enough at some plants so that the sand filters have been abandoned and replaced by a decantation process to remove the solids. At many plants decantation is part of the design of the flocculation system. Solids removal is expedited by use of vessels with cone-shaped bottoms. Frequently, the solids are allowed to accumulate from batch to batch, a practice that reduces the amount of flocculating agents required.

Secondary Treatment

Biological Treatments. Effluents from the wood preserving industry are amenable to biological treatment. Reviews of the literature on this subject were presented in both the Effluent Guidelines Development Document and in the Pretreatment Standards Draft Development Document. Data presented in those documents show that the conventional wastewater parameters —COD, total phenols, oil and grease, and suspended solids—can be reduced to acceptable levels by treatment regimes that include biological treatment. Furthermore, some preliminary evidence indicates that flocculation followed by biological treatments effectively remove the priority pollutants from these wastewaters.

Considerably less data on pentachlorophenol removal rates are available for industrial installations than for other phenolic pollutants. The reason for this is that there is no standard method for analyzing for this chemical, and the methods available to the average plant (e.g. the safranin method) are notoriously inaccurate. Moreover, neither the effluent guidelines nor most EPA discharge permits or state standards require separate monitoring for pentachlorophenol. There is, therefore, an information gap that can be filled only in part by data from studies based on bench-scale equipment and those from a single study that involved full-scale equipment.[48]

Approximately 10 percent of the wood preserving plants have biological wastewater treating facilities. The number of facilities by type reported by a sample in 1977 of 196 plants is as follows:

Trickling filter	1
Activated sludge	3
Aerated lagoon	10
Soil irrigation	8

Not included in this tabulation are several plants that use oxidation ponds alone. While it is true that some plants do obtain effective wastewater treatment with oxidation ponds, this term has come into such misuse that any body of water, including sumps, may at one time or another be described as an oxidation pond.

The characteristics of the influent to a biological treatment unit vary with the type and effectiveness of pretreatment and amount of dilution water added to the process waste. For dilution water, a few plants mix their process waste with coil condensate, boiler blowdown, etc., after flocculation and before biological treatment. For this reason, it is difficult to compute treating efficiency.

Average removal efficiency in 1977 of the treatment systems for five plants for which both raw and treated wastewater parameters were available is as follows:

Parameter	Efficiency (%)
COD.....	94.8
Phenols.....	98.2
O & G.....	90.5

Average pollution loadings at the plant outfalls are given in the following for seven plants:

Parameter	Residual Loading ($lb/1000\ ft^3$)
COD.....	2.10
Phenols.....	0.003
O & G.....	0.200

This data shows that current BAT standards can be met by treatment regimes that include biological treatment. However, there is a question of whether these standards can be met consistently by single-phase biological treatments. All of the plants for which data is given in the tables employ biological treatment that includes a high degree of redundancy. Multiphase biological treatment, in combination with appropriate primary treatment, may be required to meet current BAT guidelines. Whether this level of treatment alone will meet future criteria for priority pollutants is unknown at this point.

The effluent quality that can be achieved by a multiphase treatment regime consisting of oil separation, flocculation-filtration, and biological treatment is shown in Table 21. A single-stage biological treatment is assumed to be used. The type of biological treatment—activated sludge, aerated lagoon, or soil irrigation—is not really important, since the level of reduction shown can be obtained using any one of the three.

Potential Treatment and Control Technologies

Technologies currently used or proposed for use in industries related to wood preserving and which may have application to that industry are reviewed in the following paragraphs. A sufficient body of data is not available to provide more than an indication of the

Table 21. Quality of Effluent from Each Stage of a Multi-Phase Waste Treatment System

Parameter	Raw Waste Load	Oil Separation	Flocculation and Filtration	Biological Treatment
	(mg/liter)			
COD	21,670	6,500	3,250	500
Total Phenols	-	135	127	7.5
Pentachlorophenol	100	25	17	2.5
Oil and Grease	2,985	895	200	20

potential use of these methods with wood-preserving wastewaters.

Chemical Oxidation

Chlorination and other forms of chemical oxidation are not economically viable treatments for wood-preserving wastewater when applied before or in lieu of biological treatment. Inadequate dosage, with consequent formation of chlorophenols where none existed previously, is another problem associated with chlorination (Table 22). It is reasonable to assume that organic priority pollutants, in addition to phenolic compounds, can be adequately oxidized chemically when adequate dosages are employed; however, definitive data to support this supposition is not available.

Table 22. Chlorophenol Concentration in Creosote Wastewater Treated with Chlorine

pH	$Ca(OCl)_2$ as Chlorine (gm/liter)	Residual Phenols by Alpha Method (mg/liter)	ECD Analysis (mg/liter)	
			2,4-Dichlorophenol	2,4,6-Trichlorophenol
	0	438.5	-	-
4.5	0.5	256.1	161.0	910.7
	1.0	30.8	0	6.7
	1.5	0	0	1.5
	2.0	0	0	1.0
	3.0	0	0	0.3
	5.0	0	0	0.3
7.0	0.5	300.0	122.0	316.0
	1.0	101.5	0	35.0
	1.5	7.7	0	6.4
	2.0	0	0	2.8
	3.0	0	0	1.5
	5.0	0	0	1.3
9.5	0.5	315.4	198.0	264.0
	1.0	101.5	0	27.0
	1.5	11.5	0	25.0
	2.0	0	0	3.7
	3.0	0	0	3.8
	5.0	0	0	1.9

The use of cholorine and hypochlorites as a treatment to oxidize phenols in wastewater is widely reported in the literature. A review of the pertinent literature, with emphasis on the use of chlorine in treating wood-preserving wastewaters, was published in a recent EPA document.[49] An unpublished literature review of other chemical oxidants, including potassium permanganate, hydrogen peroxide, and ozone, that have been proposed for use with phenol-bearing wastewaters is also available.[50]

Membrane System

This term refers to both ultrafiltration, which is employed primarily to remove suspended and emulsified materials in wastewater, and to reverse osmosis (RO), which removes all or part of the dissolved substances, depending upon the molecular species involved, and virtually all of the suspended substances. Both technologies are currently used as part of the wastewater treatment system of many diverse industries[51,52] and may have potential application in the wood-preserving industry.

Ultrafiltration treatment of oily waste basically involves passing the waste under a pressure of 30 to 50 psi (0.21 to 0.35 MPa) over a membrane cast onto the inside of a porous fiberglass tube. The water phase of the waste is forced through the membrane and discarded, reused, or further processed by other means. The oil and other solids not in solution remain in the tube. The process in effect concentrates the waste. Volume reductions on the order of 90 to 96 percent have been reported.[52]

Results obtained in pilot- and full-scale operations of ultrafiltration systems have been mixed. Goldsmith et al.[52] operated a pilot unit continuously (24 hr/d) for six weeks, processing waste emulsions containing 1 to 3 percent oil. The permeate from the system, which was 95 percent of the original volume, contained 212 mg/l ether extractables—primarily water-soluble surfactants. A 4,000-gpd (15.2 m^3/d) system installed based on the pilot plant data produced a permeate containing 25 mg/l ether extractables. No significant reduction in flux rate with time was observed in either the pilot- or full-scale operation.

Ultrafiltration tests of a pentachlorophenol wastewater were conducted by Abcor, Inc. in cooperation with the Mississippi Forest Products Laboratory.[53] The samples contained 2,160 mg/l oil and had a total solids concentration of 3,900 mg/l. Flow rate through the system was 25 gpm (0.095 m^3/m) at a pressure of 48 psi (0.33 MPa). A 26-fold volumetric concentration, representing a volume reduction of 96.2 percent, was achieved. Two membrane types were tested. Both showed a flux decline on the order of 55 to 60 percent with increasing volumetric concentration. A detergent flush of the system was found to be necessary at the end of each run to restore the normal flux values of 35 gal/ft^2/d (1.4 $m^3/m^2/d$). Oil content of the permeate

was 55 mg/l. While this value represents a reduction of over 97 percent, it does not meet the requirements for stream discharge. COD was reduced 73 percent.

The principle of RO is similar to that of ultrafiltration. However, higher hydraulic pressures [400 to 600 psi (2.75 to 4.14 MPa)] are employed and the membranes are semipermeable and are manufactured to achieve rejection of various molecular sizes. Efficiency varies, but rejection of a number of salts in excess of 99 percent have been reported.[54] For organic chemicals, rejection appears to be a function of molecular size and shape. Increases in chain length and branching are reported to increase rejection.[55] Phenols are removed to the extent of only about 20 percent by cellulose acetate membranes, while polyethylenimine membranes increase this percentage to 70 but achieve a lower flux rate.[52] In case studies that have been cited, RO was found to be competitive with conventional waste treatment systems only when extremely high levels of treatment were required.[56]

Removals of 83 percent TOC and 96 percent TDS were reported for RO in which cellulose acetate membranes at 600 psi (4.14 MPa) were used.[57] Flux rates in this work of 34 to 36 gal/ft^2/d (1.36 to 1.44 m^3/m^2/d) were achieved. However, in other work, pretreatment by carbon adsorption or sand filtration was found to be necessary to prevent membrane fouling.[58] Work by the Institute of Paper Chemistry[59] indicates that membrane fouling by suspended solids or large molecular weight organics can be controlled in part by appropriate pretreatment, periodic pressure pulsations, and washing of the membrane surfaces. In this and other[60] work, it was concluded that RO is effective in concentrating dilute papermill waste and produces a clarified water that can be recycled for process purposes.

Recycling of process wastewater, following ultrafiltration and RO treatment, is the objective of a treatment installation currently being constructed by Pacific Wood Treating Corp., Ridgefield, Washington[61] (also see Case Study, later herein). The concentrated waste will be incinerated and the permeate from the system will be used for boiler feedwater. The system cost is estimated at more than $200,000.

Data on the use of RO with wood-preserving wastewater has been provided by the cooperative work between Abcor, Inc. and the Mississippi Forest Products Laboratory referred to previously.[53] In this work, the permeate from the UF system was processed further in an RO unit. Severe pressure drop across the system indicated that fouling of the membranes occurred. Permeate from the system had an oil content of 17 mg/l, down from 55 mg/l, and the COD was reduced by 75 percent. Total oil removal and COD reductions in both the UF and RO systems were 99 percent and 92 percent, respectively.

Carbon Adsorption

Adsorption isotherms have been developed for wood-preserving wastes from several plants to determine the economic feasibility of employing carbon adsorption in lieu of conventional secondary treatments.[62] The wastewater used for this purpose was usually pretreated by flocculation and filtration to remove oils. Theoretical carbon usage rates obtained from the isotherms ranged from 85 to almost 1000 lb/1000 gal (120 kg/m^3) of wastewater. With few exceptions, however, the experience has been that while activated carbon (AC) does an excellent job in removing phenolics from wood-preserving wastewater, other organics, principally water-soluble wood sugars, greatly increase carbon exhaustion rates.

Use of AC to treat wastewater from a plant producing herbicides was described by Henshaw.[63] With the exception of wood sugars, this waste was similar to wood-preserving effluents, especially as regards COD (3600 mg/l) and phenolic materials (210 mg/l). Raw wastewater was piped directly to an AC adsorber and the carbon was regenerated thermally. Flow rate and loading rate were not revealed, but the effluent from the system had a phenol content of 1 mg/l. Cost of the treatment was reported to be about $0.36/1000 gal ($0.095/m^3).

The effect of high organic content on carbon usage rate is well known in industry. Recent work to develop adsorption isotherms for 220 wastewater samples representing 75 Standard Industrial Classification (SIC) categories showed a strong relationship between carbon usage rate and organic content of the samples, as measured by TOC.[64] Usage rates as high as 1500 lb/1000 gal (179.9 kg/m^3) were reported for wastewater samples from the organic chemicals industry. For petroleum refining, the values ranged from 0.2 to 141 lb/1000 gal (0.024 to 16.9 kg/m^3) depending upon the TOC of the waste.

Use of AC in wastewater treatment in oil refineries is common.[65,66,67] Because oil refineries and wood preserving are similar in terms of wastewater characteristics, a few of the more pertinent articles dealing with AC treatment of refinery wastewater are summarized here.

Workers dealing with treatment process methodology emphasized the necessity of pretreatment of AC column influent.[68] Based on these reports, suspended solids in amounts exceeding 50 mg/l should be removed. Oil and grease in concentrations above 10 mg/l should likewise not be applied directly to AC. Both materials cause head loss and can reduce adsorption efficiency by coating the carbon particles. This is apparently more critical in the case of oil and grease than for suspended solids.

Common pretreatment processes used by the industry include chemical clarification, oil flotation, and filtration. Adjustments in pH are frequently made to enhance adsorption efficiency. An acid pH has been shown to be best for phenols and other weak acids. Flow equalization is, of course, necessary for most treatment processes.

Efficiency of adsorption varies among molecular species. In a study of 93 petrochemicals commonly

found in that industry's wastewater, adsorption was found to increase with molecular weight and decrease with polarity, solubility, and branching.[67] However, molecules possessing three or more carbons apparently respond favorably to adsorption treatments.[64]

One author[66] studied the relative efficiency of lignite and bituminous coal carbons and concluded that lignite is better for refinery wastes because it exhibits a greater surface area.

Several authors have discussed the economics of carbon adsorption. Paulson of Calgon Corp. reports that direct operating costs based on BOD removal from refinery wastewater range between 4.8 and 10.9 cents/1000 gal (1.26 and 2.88 cents/m^3) for primary effluents and between 5.3 and 9.4 cents/1000 gal (1.40 and 2.49 cents/m^3) for secondary effluents. These estimates were based on a carbon usage rate of 9.9 lb/1000 gal (1.19 kg/m^3). Much higher operating costs for AC systems have been reported by Rosfjord, et al.[69] Costs of $0.40 to $6/lb ($0.88 to $13.24/kg) of phenol removed were cited. The efficiency of the carbon regeneration facilities were listed as an important consideration in computing operating costs. Recovery of chemicals, particularly phenols, from carbon beds by either reactive or solvent methods was reported to be less costly than thermal regeneration.

According to Hutchins,[56] it is most economical to discard carbon at usage rates lower than 350 to 400 lb/d (158.5 to 181 kg/d) and to regenerate thermally at higher usage rates.

Limited data on AC treatment of wood-preserving waste strongly indicates that the process is not economically viable when applied as a secondary treatment. The high cost of carbon adsorption when employed in this capacity is primarily due to the presence of high wood sugar levels in the effluents from this industry. Use of the process as a tertiary treatment following biological oxidation—assuming a high oxidation efficiency of the sugars—may be economically viable.

Adsorption by Other Media

Polymeric adsorbents have been recommended for use under conditions similar to those where carbon adsorption is indicated.[70] Advantages cited for these materials include efficient removal of both polar and nonpolar molecules from wastewater, ability to tailor-make an adsorbent for a particular contaminant, small energy inputs for regeneration compared to carbon, and lower cost compared to carbon where carbon depletion rates are greater than 5 lb/1000 gal (0.601 kg/m^3). Data on efficiency of polymeric adsorbents were not presented. Clay minerals, such as attapulgite clay, have been recommended for use in removing certain organics and heavy metals from wastewater.[71]

New Preservatives

An obvious solution to the pollution problems confronting the wood-preserving industry is to develop new preservatives that are both environmentally compatible and equally as effective as those presently in use. This solution is not practical. There are many candidate wood preservatives currently being screened; however, some of these cannot be registered because of the same objections made against preservatives currently being used. Other new preservatives undoubtedly will prove to be ineffective, and none of them has been tested sufficiently to warrant commercialization. Furthermore, no single preservative can replace fully the system of preservatives now used by industry, regardless of how good it may be.

At least one or two of the new preservative formulations being studied look promising, based on laboratory tests. Field testing has begun, but it will take 5 years to complete and additional service tests will be required. The consensus is that the prospects are poor for finding replacements for creosote, pentachlorophenol, and the salt formulations within the next decade.

New Processing Technology

A new processing technology has been developed to reduce the volume of wastewater that must be treated. The process has been successfully tested at the pilot-scale level, but not on a commercial scale. In the process, the pentachlorophenol is deposited in-situ following treatment of wood with a water-soluble salt of that chemical. Wastewater generated during treatment can be recycled to prepare new batches of treating solution.

Wastewater Disposal-Evaporation Processes

Evaporation has been most widely accepted by the industry as the principal method of wastewater disposal. Some applications of evaporation by the industry are both economical and effective, while others are not. Evaporation methods that require the use of process steam are not considered economical. On the other hand, methods that depend on simple surface evaporation from lagoons may be economical but are not effective, since such installations usually are located in regions where rainfall equals or exceeds lake evaporation.

The use of one or more evaporation lagoon equipped with spray equipment is the most effective and economical method. By proper sizing of the lagoons to account for seasonal differences in both rainfall and evaporation, a zero discharge of process wastewater can be achieved. Actually, such installations serve a dual purpose. In addition to evaporating all or most of a plant's effluent, significant reductions in conventional wastewater parameters are achieved with only a minimal accumulation of sludge, since an evaporative lagoon functions in much the same fashion as an aerated lagoon. Cooling towers that utilize waste heat for wastewater evaporation are equally as effective and much more efficient in terms of load requirements. A closer look at selected evaporation processes, particu-

larly with respect to Boulton processing plants in the west, is presented in the following paragraphs, along with energy and cost data.

Forced Evaporation

Equipment for forced evaporation can take several forms. All require considerable quantities of energy. The most common in use in the wood treating industry is an open pan heated by gas, oil, or steam coils.

Roughly 1000 Btu/lb (1055 kJ/lb) of water are required to evaporate water, depending upon the temperature at which the evaporation takes place. A Boulton plant treating 2000 ft^3/d (56.63 m^3/d) (1 retort) of green stock [at 22.6 lbs water/ft^3 (362 kg/m^3) stock] requires 45 million Btu (47.47 million kJ) per day to evaporate the wastewater. At an energy cost of $1.4/million Btu ($1.32/million kJ) based on a regulated natural gas price of $1.45/1000 ft^3 ($0.051/m^3) and an evaporation efficiency of 58 percent, evaporation costs are $119 per day or $38,000 per year.

Similarly, a plant treating dry stock will have an evaporation energy cost of $26.40 per day or $9240 per year. As energy costs increase, the cost of forced wastewater evaporation also will increase. If waste wood is being used as boiler-feed then forced evaporation costs will be much lower.

The energy saving advantages of using pre-dried stock are obvious. Most treating plants will use a mixture of pre-dried stock, the dryness of the stock depending upon the season, storage yard capacity, and product demand. Any shift toward using dryer stock will reduce the quantity of water to be evaporated and thereby the cost.

Evaporation Containment Ponds

Evaporation containment ponds can be used in areas where land is available at a low enough cost to be economical and where the yearly evaporation rate exceeds the yearly rainfall plus wastewater generated. In eastern Oregon and Washington, pan evaporation is 30 to 40 in (76.2 to 101.6 cm) per year, and in California, 40 to 50 in (101.6 to 127 cm) per year. Rainfall in eastern Oregon, Washington, and California is less than 20 in (50.8 cm) per year, so evaporation containment ponds are feasible there.

Adding a spray system to an evaporation pond will increase the rate of evaporation by exposing greater quantities of water to the air. This sytem will reduce the size of the evaporation pond required to evaporate rain and wastewater. The size of an evaporative containment spray pond depends heavily on climatic conditions.

Use of Waste Process Heat for Evaporation

Waste process heat is produced whenever part of the process is being cooled, for instance in condensers and compressor coolers. The waste heat is removed from the process by cooling water. This heat can be used to evaporate treated wastewater in spray cooling ponds or cooling towers. At the 1972 Annual Meeting of the American Wood Preservers Association, Charles Best described four such systems that have been in operation since before 1971. Figure 15 shows how such a system would be connected.

Heat is applied to the preserving cylinder via steam coils while a vacuum is used to evaporate water from the stock. The heat contained in the water vapor that leaves the cylinder is transported to the condenser, where it enters the cooling water. The water is cooled in a cooling tower or spray pond, and the heat is transferred to the air in the form of water vapor. The amount of heat absorbed by the cooling water is slightly more than is required to evaporate the water. Additional heat is obtained from oil condensation in the condenser and cooling of the condensate to below the boiling temperature. The following heat and water balance demonstrates that there is sufficient heat available to evaporate all of the process water. There is insufficient heat available to evaporate rain water.

Vapors from retort:
7.5 lb/ft^3 (120 kg/m^3) for partially dried stock
20 lb/ft^3 (320 kg/m^3) for green stock

Energy from retort contained in vapor at 200°F (93.3°C):
8594 Btu/ft^3 (320 MJ/m^3) for partially dried stock
22,916 Btu/ft^3 (853.5 MJ/m^3) for green stock

Rain water addition:
2 lb/ft^3 (32 kg/m^3) (yearly average)

Wastewater to be treated:
9.5 to 22 lb/ft^3 (152.2 to 352.4 kg/m^3)

Heat added to cooling water [vapor condensed to 100°F (37.7°C)]:
8034 Btu/ft^3 (299.2 MJ/m^3) for partially dried stock
21,557 Btu/lb^3 (802.8 MJ/m^3) for green stock

Heat added to cooling water via wastewater at 60°F (15.5°C):
266 Btu/ft^3 (9.9 MJ/m^3) for partially dried stock
616 Btu/ft^3 (22.9 MJ/m^3) for green stock

Water evaporated from cooling tower at 1065 Btu/lb (2477 kJ/kg):
7.8 lb/ft^3 (125 kg/m^3) for partially dried stock
20.8 lb/ft^3 (333 kg/m^3) for green stock

Cooling System Design

Design of a cooling tower or spray cooling pond must take into consideration optimization both of cooling and of evaporation performance. The cooling water temperature must be low enough so that existing condensers can be used and process vacuums can be maintained. An additional advantage to lower cooling water temperatures is that evaporation is enhanced. These lower temperatures are achieved by cooling facilities larger than normally would be considered if cooling were the sole objective.

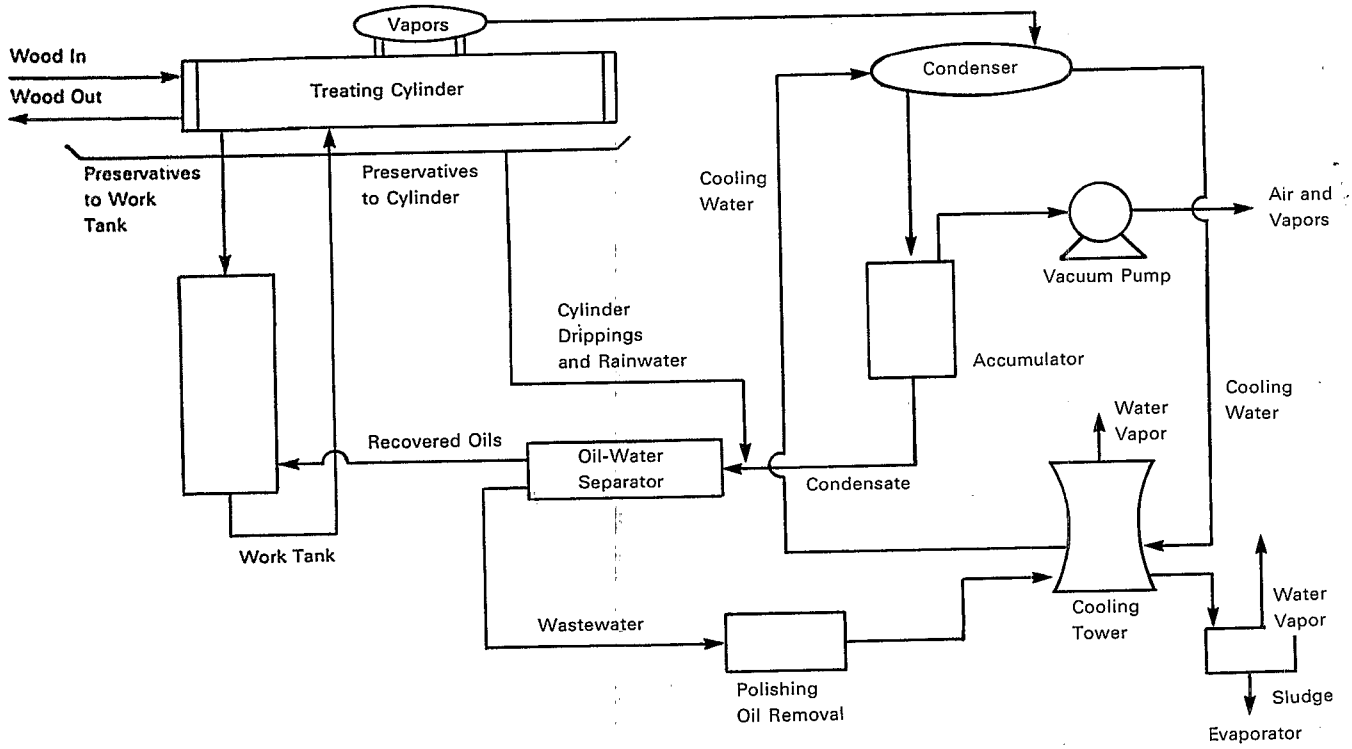

Figure 15. Diagram of a Boulton Process Wood Treating Plant Using Waste Heat for Evaporation of Wastewater.

Cooling systems designed for maximum evaporation should operate with the hot water input temperature as low as possible to avoid heat loss. Air leaving the cooling system will be heated to a temperature near the hot water temperature. When the exit air temperature is above the atmospheric air temperature, energy escapes into the air and less is available to evaporate water. Figure 16 illustrates the amount of evaporation achievable from a cooling pond with a constant heat input, but with varying flows and thereby different cooling ranges. The cooling range is the difference between the hot and cold water temperatures entering and leaving the cooling pond/tower.

Also shown in Figure 16 is the volume of wastewater evaporation corresponding to the heat input from a one-retort wood treating plant (does not include rain water). In order to evaporate all of the wastewater, a cooling range of less than 10°F (5.6°C) is required. Figure 16 was developed for the month of March in Portland, Oregon. During other months the evaporation rate would be different. Low cooling water temperatures are attained by high cooling water flow rates through condensers or by cooling water recirculation through the cooling tower.

Evaporation from a cooling tower is closely tied to the liquid-to-gas (L/G) ratio. When gas flow rates are large compared to liquid flow rates (low L/G), more evaporation takes place. Figure 17 shows the amount of evaporation that may be expected from a one-retort wood treating plant at several L/G ratios. Cooling towers normally are designed to operate with an L/G ratio of about 1, and spray cooling ponds with an L/G ratio of between 0.10 and 1.0.

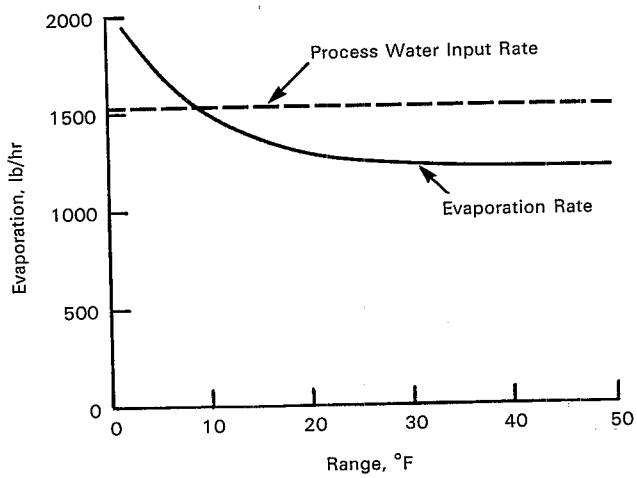

Figure 16. Evaporation Rate of Water from a Cooling Tower as a Function of the Difference Between Cooling Water Inlet and Outlet Temperatures at a Constant Heat Input.

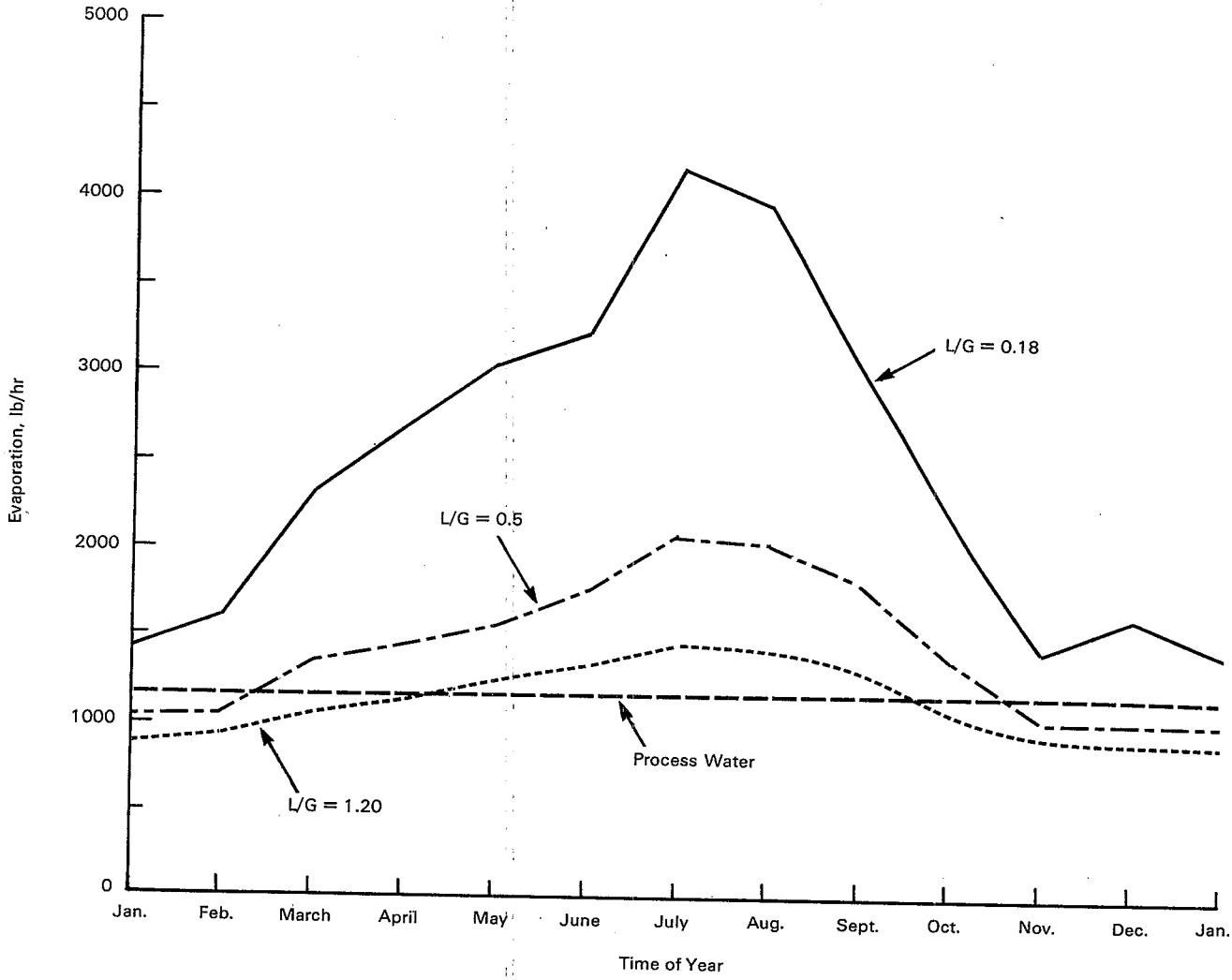

Figure 17. Cooling Tower Evaporation Rate for Several Liquid-to-Gas Ratios.

When a cooling tower is designed with a low L/G ratio, the exiting cooling water temperature, within limits, will be lower than when high L/G ratios are used. The lower exiting cooling water temperature will result in a lower entering cooling water temperature and more evaporation will result.

Cooling Pond Design and Operation

A cooling pond was designed for a maximum of 5° F (2.78° C) rise in cooling water temperature in the condenser when green stock is being conditioned. The resulting cooling water flow through the condenser for one retort treating 1600 ft^3/d (45.30 m^3/d) was 650 gpm (0.04 m^3/s). The cooling pond dimensions were 100 ft by 134 ft (30.48 by 40.84 m) and with 17 spray nozzles spaced 2 ft (61 cm) apart, resulting in L/G of 0.24 for a 5-mph (8.04 km/h) wind. The summertime maximum cold water temperature is 70°F (21°C).

Figure 18 shows the evaporation attainable from such a pond located in Portland, Oregon, over a year's time when the condenser is being operated at 78-percent capacity. Also shown in Figure 18 is the amount of process water that requires evaporation, and the amount of process water and rain water that falls on the retorts and vicinity, tank farm, and in the cooling pond. As can be seen from the graph, in the winter the cooling pond will be unable to evaporate all of the process and rain water; however, evaporation during the summer months will be in excess of the process and rain water collected. The yearly average evaporation for the pond will be in excess of the water addition.

Storage must be considered to accommodate the winter rain water. The unevaporated process and rain water will be 20,000 ft^3 (566.33 m^3) for the winter season for an average year. The cooling pond used in this example has a surface area of 13,400 ft^2 (1244.9

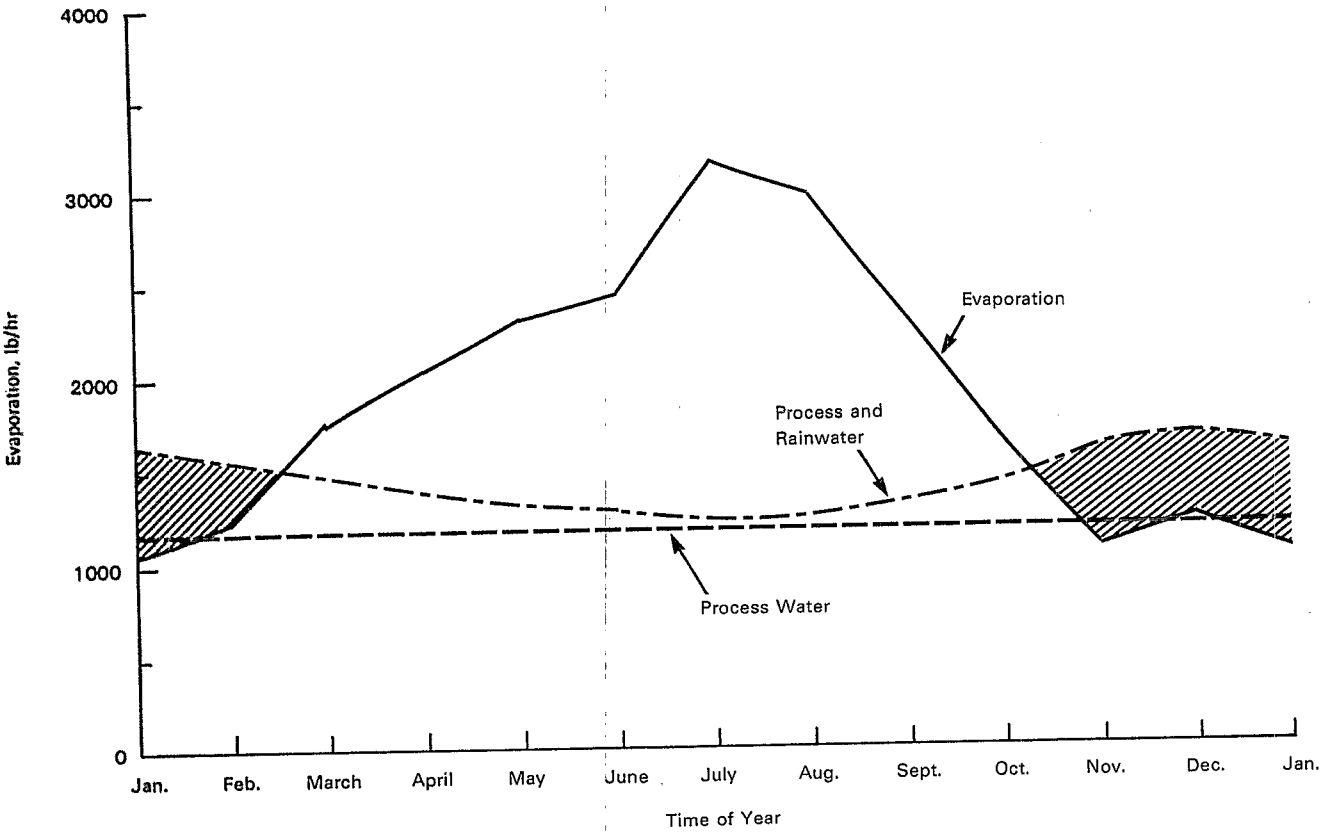

Figure 18. Spray Cooling Pond Evaporation Rate Over One Year.

m^2), in which the accumulated rain would cause a level rise of 8 in (20.32 cm). A cooling pond with 2 ft (61 cm) of freeboard could accommodate storage of excess rainwater even for exceptionally wet years. In drier climates, such as east of the Cascades or in California, evaporation will exceed rainwater encountered.

Cooling Tower Evaporation Performance

A cooling tower was designed to cool 650 gpm (0.04 m^3/s) of condenser water heated 5°F (2.78°C) from a retort treating 1600 ft^3 (45.30 m^3) green stock per day. The L/G ratio was 0.5, somewhat lower than normal cooling tower design. The summertime maximum cold water temperature was 75°F (23.8°C). Figure 19 shows evaporation from the tower over the span of one year when the tower was operated at 78-percent capacity. Also shown is the quantity of process and rainwater that needed to be evaporated.

As can be seen from Figure 19, a cooling tower of the design described is unable to evaporate all of the process and rainwater accumulated during the winter months. Excess evaporation takes place during the summer. Over an entire year, there is more evaporation than wastewater input.

To accommodate the excess process and rainwater during the winter months, storage capacity needs to be built. Excess water collected over a winter averages 16,400 ft^3 (464.39 m^3). To accommodate this water in wet years, a 200,000- to 300,000-gal (757.08 to 1135.6 m^3) tank will be needed. An alternative is to install excess fan horsepower in the cooling tower to increase the L/G as needed.

Retrofitting to Existing Plants

An evaporation system with a spray cooling pond or cooling tower of sufficient size and proper cooling rate to evaporate process and rainwater from a wood treating plant is apt to be limited by the size of the existing condenser. The small cooling ranges required for good evaporation dictate high cooling water flows through the condenser and thus small temperature gains. To circumvent installation of a larger condenser, the normal quantity of cooling water can be used through the condenser and the bulk of the cooling water can be recirculated through the cooling pond or tower, mixing the hot condenser water with it.

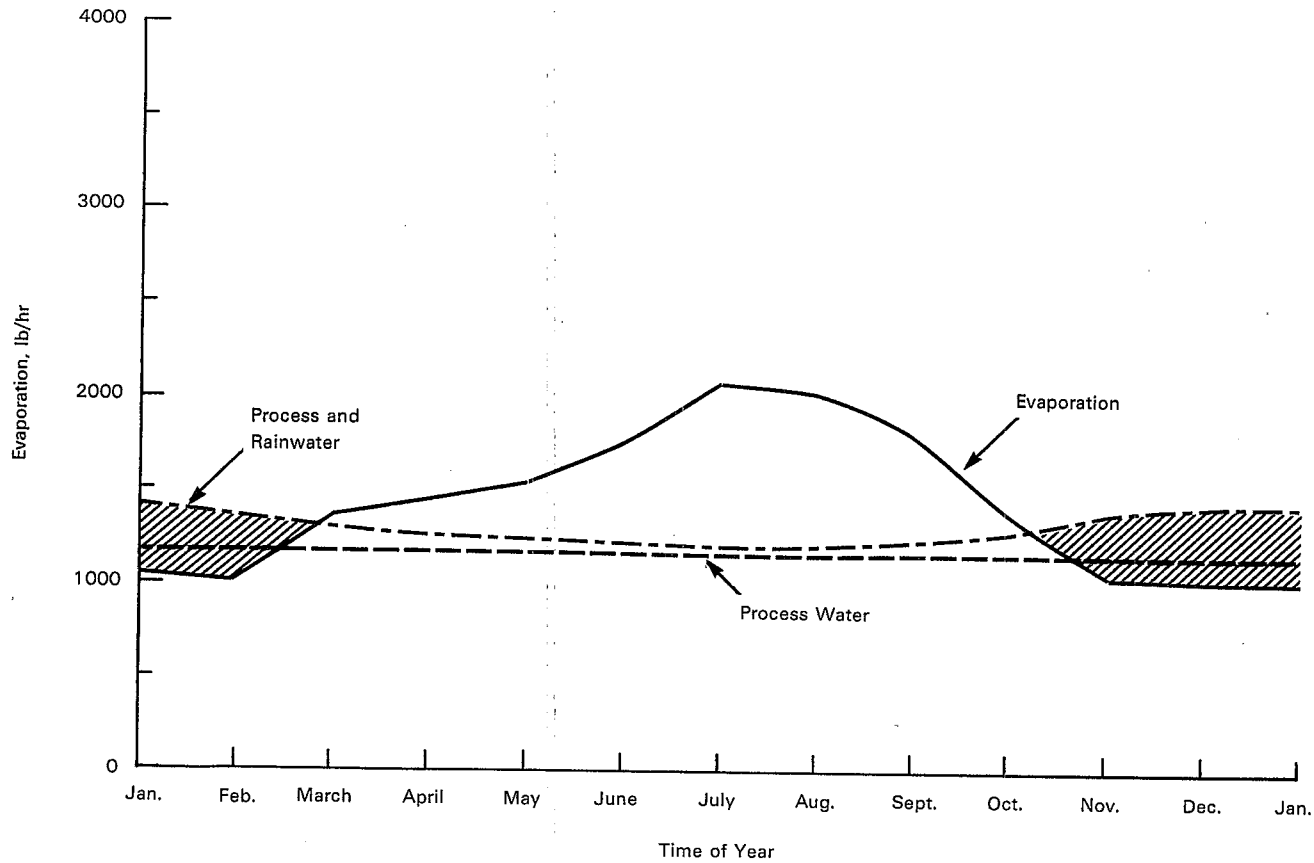

Figure 19. Cooling Tower Evaporation Rate Over One Year.

Evaporative Process Operational Problems

Volatile Compounds. Regulatory agencies are primarily concerned with the quantity of volatile toxic compounds introduced into the air by evaporation of wood-treating wastes, a number of which are known to exist. The fate of these compounds in the several evaporative processes is unknown. Many of the compounds are known to be volatile. As a result, EPA is initiating a project to measure these volatile compounds.

To avoid evaporation of these toxic compounds into the air, good oil-water separation and secondary polishing oil removal must be provided. Many of the volatile compounds are insoluble in water and will be removed in the oil phase. However, such compounds as phenols that cannot be removed by oil-water separation will be passed on to the cooling tower and evaporated to the air.

Corrosion. Corrosion in operating systems has not been a problem. Since all the water added to the cooling water system is essentially distilled water, there is no build up of salts and no need for a blowdown. Sludge accumulates in the system and needs to be disposed of periodically. Sludge accumulation may be about 4000 gal/yr (15.14 m^3/yr).

Fouling. Fouling of condenser tubes can be a serious problem. Preservatives and dissolved wood compounds tend to polymerize with time and heat and coat the insides of pipes and condenser tubes. In one plant, fouling made it necessary to remove the compressor from the recirculated cooling water system. Plants using barometric condensers will not encounter fouling problems.

Pretreatment of wastewater prior to disposal into the cooling pond or tower may be necessary to prevent fouling. One preserving plant uses a sequence of gravity oil and water removal, lime flocculation, filtration, and an aerated lagoon to treat wastewater. Another plant adds its wastewater, after gravity oil and water separation, to its cooling water. The cooling water passes through a spray cooling pond, an aerated lagoon, a holding pond, and then back to a surface condenser.

Comparative Economics

Economics is the guiding factor in selecting a wastewater disposal system. With energy being a

strong factor in the economics of one such system, costs are difficult to assess. Two scenarios are presented in the following paragraphs: one at approximately today's energy costs and one at double today's energy costs.

Table 23 shows approximate capital costs and Tables 24 and 25 show approximate operating costs for each of the systems. As can be seen, the system using a cooling tower is the most expensive in terms of both capital and operational costs. The high operating cost results from the high amortization expenses caused by large capital costs. As energy becomes more expensive, though, the cost of wastewater evaporation by use of cooling tower and forced evaporation become more comparable.

Forced evaporation is the second most expensive system and will become even more expensive as energy prices continue to rise. Operational costs are highest when green stock is being treated and more tolerable when pre-dried stock is being treated. The least expensive method for disposal of treating plant wastes is evaporation by spray cooling ponds.

Table 23. Capital Costs of Evaporation Systems

Tray Evaporator, 200 ft^2	$ 26,000
Cooling tower, 650 gpm	$160,000
Storage tank, 300,000 gal	65,000
Flocculation-filtration	25,000
Total	$250,000
Spray pond (140 × 100 ft × 6 ft Land)	5,000
630,000 gal:	
Materials	5,000
Labor	10,000
Pumps	3,000
Piping	2,000
Misc. Elec.	2,500
Engineering	3,000
	$ 30,500
Flocculation-Filtration	25,000
Total	$ 55,500

Table 24. Operation Costs of Evaporation Systems

Tray evaporation:	
Interest and Capital Payments	$3,418
Depreciation (15 yr)	1,800
Energy	9,200-38,000
Maintenance	1,000
	$15,400-45,200
Cooling tower:	
Interest and Capital Payments	$32,868
Depreciation	16,700
Energy	10,000
Maintenance	7,500
	$67,100
Spray pond:	
Interest and Capital Payments	$ 7,296.79
Depreciation	3,700
Energy	5,000
Maintenance	1,700
	$17,700

Table 25. Operation Costs of Evaporative Systems at Twice Today's Energy Costs

Tray evaporation:	
Interest & Payments	$3,400
Depreciation	1,800
Energy	18,400-76,000
Maintenance	1,000
	$24,600-82,200
Cooling tower:	
Interest & Payments	$32,900
Depreciation	16,700
Energy	20,000
Maintenance	7,500
	$77,100
Spray pond:	
Interest & Payments	$ 7,300
Depreciation	3,700
Energy	10,000
Maintenance	1,700
	$22,700

Case Study: Wet Decking with Water Recycle

The Pinecrest Lumber Company, a wholly owned subsidiary of Green Bay Packaging Incorporated, is located near Menifee, Arkansas, about 35 miles (56.32 km) northwest of Little Rock. It is a chip-and-saw operation supplying chips to Arkansas Kraft Corporation, another Green Bay Packaging subsidiary, which operates an unbleached kraft linerboard mill. Pinecrest started operations in November 1973. About one-quarter of its raw materials come from 150,000 acres (607 km^2) of Arkansas Kraft woodlands and the rest from private lands. The majority comes from within a 50-mile (80.46 km) radius of the mill. The predominant species is shortleaf pine, with about 5 percent loblolly. Forest planting operations are predominantly loblolly.

The nominal capacity is 140,000 board-feet (fbm) per day (330.4 m^3/d) in a two-shift operation. Logs are mechanically barked in a 26-in (66 cm) ring barker. A chip-and-saw unit reduces one dimension to 4 in (10.16 cm), followed by a vertical saw arbor for conversion of the center cant to two-by-fours, which make up 80 percent of production. Additional chips are generated in a chip-and-saw, two-side edger. Two-in (5.08 cm) lumber is produced in widths to 12-in (30.48 cm) and 1-in (2.54 cm) lumber to 6 in (15.24 cm). A high-temperature, gas-fired, 24-hr kiln completes the processing.

Dry storage of logs reduces lumber quality by allowing the growth of blue stain. In addition, bark beetles do severe damage by boring. The pulp mill prefers never-dried chips to produce higher strength pulp and to prevent yield losses in byproduct turpentine and tall oil. For these reasons, the logs are kept wet during storage by wet decking. Logs have been stored wet for up to 14 months, with no adverse results. Logs have been successfully stored in this manner up to 4 years, according to the experience of nearby operations.

Log lengths are from 10 to 20 ft (3.04 to 6.08 m) and average about 9-in (22.86 cm) in diameter at breast height (dbh). As many as six rows may be formed side-by-side with no intermediate access aisle. Six rows can be well covered with four rows of sprinklers. As many as 11 rows can be accommodated using the entire deck, but 8 rows is the usual maximum.

Yard inventorying of logs is highly variable, depending on woodlands conditions. During periods of heavy rainfall, which restricts logging, the wet deck is used to supply the mill. To avoid double handling, the preferred operation is to bypass storage, but that balance cannot be maintained. It is not practical to sprinkle logs if less than two rows are stored, since the spray pattern converts the adjacent access areas to mud. Concrete pads are being considered seriously to eliminate the mud problem and to assure front-end loader maneuverability without having to dry out the aisles between piles. If possible, first in-first out storage is practiced.

Wet decking of stored logs was started in April 1976. Logs are piled 12 to 15 ft (3.66 to 4.57 m) high in 300-ft (91.44 m) rows. Drainage from the 2.8-acre (11,330 m^2) wet deck flows to a 1.3-acre (5261 m^2) sedimentation pond about 5 ft (1.52 m) deep, with a capacity of 7.5 acre ft (9250 m^3). Excess drainage following settling of solids overflows to a second 1.1-acre (4452 m^2) pond having a depth of 5.5 ft (1.67 m) and a 5.7-acre ft (7031 m^3) capacity.

Water is pumped from either pond, as chosen, to feed the sprinkler system. The sprinkler system was designed according to recommendations of the sprinkler manufacturer, based mainly on irrigation criteria. The pump is a 30 hp (22 kW), high-head centrifugal pump with a capacity of 350 gpm (0.022 m^3/s) at 100 psi (689 kPa). The normal operating range is 40-100 psi (276-689 kPa). The water is pumped to the wet deck area via 300 ft (91.44 m) of a 4-in diameter (10.2 cm) pipe. The sprinkler pipe on the long piles is 2-in diameter (5.08 cm), quick-couple, aluminum irrigation pipe with 3/16-in or ¼-in (0.48 or 0.64 cm) rainbird units every 20 or 40 ft (6.09 or 12.2 m). With an approximately 60 ft (18.28 m) spraying diameter, there is ample overlap to cover the entire area. Pipe length is chosen to fit the pile contour. The sprinkler orifice diameter may be changed to improve spray coverage. As many as six rows totalling 1,800 ft (548.6 m) of 2-in (5.08 cm) pipe have been used. The rainfall equivalent of 150 gpm (0.01 m^3/s) on 1.5 acres (6071 m^2) is 5.33 in (13.53 cm) per day.

Orifice plugging is not a serious problem. A wire cage with ½-in (1.27 cm) spacing protects the foot valve, which itself has a 3/16-in (0.47 cm) screen. These screens have not required cleaning to date. It was found that sprinkler pluggage was essentially eliminated

by terminating each line with a cap having a ½-in (1.27 cm) diameter hole through which a flushing flow is continuously passed.

A few comments should be made about the history of regulations on wet decking. The EPA published a Development Document[72] in August 1974, which included a study of wet decking by Environmental Science and Engineering, Inc., of Gainesville, Florida. They examined practices at eight West Coast mills and six mills from the Southeast and South. Among these 14 installations, they found that recycling was more commonly used in the Southeast and South than in the West. The sprinkler flow-to-log inventory ratio varied by a factor of 15, comparing maximum to minimum, showing the great variability in these operations. They chose for a typical Southern wet deck, with recycle, a hydraulic flow of 150 gpm (0.57 m^3/min) onto 4,600 yd^3 (35,169.5 m^3) of logs and a deck area of 4 acres (1618.8 m^2). Although Pinecrest can be considered in this flow range, the company's stored log volume would often be three to four times this 4,600 yd^3 (3517 m^3) figure. Presumably Pinecrest's larger inventory would increase the amount of water lost by evaporation in comparison with EPA's typical mill.

The Development Document recommended that Best Practical Control Technology Currently Available (BPT) for the wet storage subcategory should call for "no discharge of process wastewater pollutants between May 1 and October 31, except a volume of water equal to the difference between the mean precipitation for a given month and 10 percent of the annual lake evaporation; no discharge of process wastewater pollutants between November 1 and April 30, except a volume of water equal to the mean precipitation that falls on the drainage area of the wet storage facility." When a discharge was allowed, the debris could not exceed 1 in (2.54 cm) in diameter and the pH was limited to the range 5.5 to 9.0.

The same limitations were recommended for Best Available Technology Economically Achievable (BAT) and, for wet decking only, for New Source Performance Standards (NSPS). These proposed regulations were published in the *Federal Register* on August 26, 1974.

Following study of comments on the proposed regulations, final wet decking regulations were promulgated in the *Federal Register* on January 16, 1975. The limitation on debris diameter was kept, but the pH range was changed to 6.0 to 9.0 and the flow limitation was dropped.

Water Balance

Rainfall records from the U.S. Weather Bureau show that the Little Rock area has had about 48 in (121.9 cm) of annual rainfall. The *Climatic Atlas* indicates that the mean annual lake evaporation has been 43 in (109.2 cm). (Using these figures, the originally proposed regulations would have meant no allowable discharge in the months of June through October.) Various estimates of evaporation rates from a sprayed wet deck have been in the neighborhood of 30 percent of the applied water to 0.1 gal/ft^2/d (0.004 m^3/m^2/d) with an equal gallonage lost to absorption and percolation.

Approximate water balances were calculated using both estimates and the following assumptions:

- 150 gpm (0.564 m^3/min) sprinkler flow
- 12 month operation
- 3 acres (12,141 m^2) of log deck, one-half under spray
- 2.5 acres (10,118 m^2) of ponds
- 50 in (127 cm) of annual rainfall
- 43 in (109.2 cm) of annual evaporation from ponds
- Case I: 30 percent of applied spray lost
- Case II: 0.2 gal/ft^2/day (0.008 m^3/m^2/d) lost

For Case I, there would be an annual loss prediction of 19.5 million gal (73,815 m^3) or 30 gpm (0.114 m^3/min). For Case II, the annual loss prediction was 0.3 million gal (1135 m^3) or 0.6 gpm (0.0027 m^3/min). An existing on-site well could supply the deficit in Case II but not Case I. There was actually more short-term concern for water shortage than for pond discharge.

In view of the predicted deficit, EPA, Region VI, was provided an Affadavit of No Discharge. The affadavit was filed in December 1976, after 7 months of operation. The water level in December was essentially the same as when spraying had started. The 1976 rainfall at Little Rock was about 10 in (25.4 cm) below normal although no records were available to document the actual on-site precipitation. It was estimated that three or four successive years, each with 10 percent higher than normal rainfall, could cause the ponds to crest and 1 year with 25 percent higher than normal rainfall could be expected to produce similar results.

Little Rock rainfall records for the previous 98 years were grouped in sets for each 5 percent greater than the mean, or roughly 2.5-in (6.35 cm) intervals above 48 in (121.9 cm). The records show that 125 percent of the average annual rainfall has been reached, or exceeded, in 13 years out of 98, 150 percent was reached or exceeded in 2 years out of 98, and the highest year out of the 98 was 157 percent of the average.

Pinecrest has an inadequate data base on which to speculate about the future of the ponds. Records are now being kept of pond height in an attempt to relate spraying history and rainfall to observed pond height.

Case Study: Wastewater Handling at Boise Cascade's Elgin, Oregon Site

Boise Cascade acquired a studmill at Elgin, Oregon in 1961. The mill was modernized and a plywood plant was built on the site.

The logs in the storage area were being sprinkled from Phillips Creek, which borders the log yard. The creek was inadequate, since it goes dry in late July, just when the water was really needed. With the additional storage of logs required because of the additional production, a new water source was urgently needed. Accordingly, a well was drilled and an artesian aquifer encountered. A pump capable of delivering 1500 gpm (5.67 m^3/min) at 100 psi (689 kPa) was installed.

This arrangement provided a satisfactory water source for the logs, but a wastewater problem developed, since the contaminated water could not be routed to Phillips Creek. The waste stream included not only log-yard runoff from summer sprinkling, but miscellaneous waste streams from processing that flowed year around. It was decided at that time to purchase a section of flat land, divert the wastewater to this area and flood irrigate the land. The irrigation benefited both a hay crop and cattle grazing.

As time passed, stricter regulations became effective and Boise Cascade could no longer flood the flat land because of runoff to the Grande Ronde River. To avoid this, it was decided to install a sump pit, catch the runoff, and recycle it back to the log decks. The logs were sprinkled from April 1 to December 1 from the recycled runoff. From December 1 to April 1 the mill's permit allowed a discharge to Phillips Creek. Subsequent to the enactment of the Water Pollution Control Act Amendments of 1972, even stricter permit requirements were imposed. The plant had to face the question of proper disposal of process wastewater, log-pond overflow, storm runoff, and water from numerous surface springs without dumping any contaminated water into an adjacent freshwater stream. There was also the problem of year-round excess water in the log yard.

The sources of clear and contaminated wastewater were freshwater springs in the log yard; plant site and log pond; surface storm runoff; equipment cooling water; plant process wastewater, including boiler blowdown water; and log-pond overflow water. Because the waste discharge permit issued by Oregon's Department of Environmental Quality forbids contaminated water discharge, each of these water sources had to be considered individually. The most difficult problem was Phillips Creek, which runs along the west and south sides of the log yard. Many years ago the stream ran along the north side of the present log yard, but heavy runoff caused flooding and the creek changed to the present stream bed. It was suspected that the source of many of the freshwater springs in the log yard and around the plant site came from the adjacent stream.

A series of test holes were dug in various parts of the log yard and the data gathered from them indicated that the stream was indeed providing the unwanted water to the surface springs. From the test-hole data a French drain was designed that would intercept the fresh clear spring water and return it to the freshwater stream downstream of the log yard. The Department of Environmental Quality had no objection to returning uncomtaminated spring water to the stream.

The 1500-ft long (457.2 m) French drain was constructed across the log yard using concrete pipe set in clean gravel at the depth of the hardpan, about 8 to 10 ft (2.43 to 3.0 m) below the ground surface with a drainage slope toward the stream. A 1½-in (3.81 cm) space was left at each pipe joint to allow water inflow. The open joints were covered with wire mesh to keep gravel and dirt from entering the pipe. The pipe was covered with clay to a depth of 2 ft (61 cm) above the pipe and firmly compacted; the clay provided a seal so that contaminated log yard surface water could not leach down into the uncontaminated fresh water. The balance of the French drain trench was filled with gravel from the excavation. After a short flush-out period, the French drain stabilized to a clear freshwater flow of about 200 gpm (0.757 m^3/min). It was not long before it was noted that previously wet areas in the log yard had dried up. A lowering of the water table downstream from the French drain was also noted.

Collection of contaminated wastewater was accomplished through two collection systems. The first system collected log yard runoff, storm runoff, plant wastewater, surface spring water around the sawmill, and all the machinery cooling water. Because of the scattered nature of the cooling water, no attempt has yet been made to collect and dispose of it separately. Two collection culverts transported all of this wastewater to an 11,000-gal (41.6 m^3) collection sump located at the southeast corner of the plant site.

Due to the special nature of boiler blowdown water, a separate collection sump, pump, and pipeline

were used to move this wastewater to the lagoon system. A collection sump near the boiler house provided a base for the two 25-hp (18.64 kW), 4-in (10.2 cm) sump pumps. The two pumps, piped in parallel, pump the blowdown water through a pipeline to the wastewater settling lagoon. Only one of these pumps is used at any one time; the other one is available on a standby basis.

Since there are several opportunities for debris to enter the wastewater collection system, a rotating screen was installed to pick up and dispose of any material that could prove harmful to the pumps. A pump station was built at the collection sump so that the accumulated wastewater could be moved to the settling and storage lagoons. Two, 1500-gpm (5.68 m^3/min) sump pumps, piped in parallel to a common manifold, and each powered by a 40-hp (29.83 kW), 1800-rpm electric motor, provide the necessary pumping capacity to move the wastewater through the 1100-ft (335 m) pipeline. Only one of the pumps is used at any one time. The second pump, on a standby status, will start automatically should the first pump fail. A signal light, mounted on top of the pump house, informs operating people in the log yard a quarter mile away if any equipment in the pump station fails.

A pipeline over 1100 ft (335.28 m) long was installed to lift the wastewater more than 60 ft (18.28 m) from the collection sump to the settling lagoon. The pipeline, 12-in (30 cm) PVC pipe, had to cross the fresh water stream. The stream crossing was accomplished with the use of two 60-ft (18.28 m) Douglas fir logs.

The settling lagoon is about 6-ft (1.82 m) deep and contains 17 acre ft (20,970 m^3). All the contaminated wastewater from the collection sump and boiler blowdown sump end up in the settling pond. The lagoon acts somewhat like a pretreatment pond or clarifier, in that all the settleable solids are deposited in this pond. This lagoon also acts as a water disposal site, in that it has a large evaporating surface. Maintenance on the settling lagoon consists of draining and dredging every 8 to 10 years.

From the settling lagoon the wastewater passes through a 120°F (48°C) weir into the storage lagoon. Associated with the weir is a float recorder/totalizer with a 60-day chart. With this recorder, the daily and seasonal variations in the wastewater production can be monitored.

The wastewater is used for sprinkling on the log yard for about 7 to 8 months of the year. Since production of wastewater continues over the full year, a storage lagoon became necessary. A site was chosen adjacent to the already existing settling lagoon. The storage lagoon has a capacity of over 136 acre ft (167,800 m^3), or over 44 million gal (166,540 m^3). About 55,000 yd^3 (42,050 m^3) of material was excavated from the lagoon site and placed in dikes in the construction of this facility.

The storage lagoon was constructed entirely from materials found on the site. The dike core was formed from clay and silty clay soils to secure a waterproof seal for water containment. The surface of the dike was covered with topsoil taken from the bottom of the lagoon. The topsoil provides a good medium for revegetation. The inside of the dike was covered with 2 ft (61 cm) of gravel to prevent wind and wave action erosion. Filling of the storage lagoon begins at the end of each water disposal season.

In addition to storage, the lagoon provides a very large evaporation surface. For example, with a wastewater temperature of 50°F (10°C), an air temperature of 80°F (26.6°C), a lagoon surface area of 19 acres (76,900 m^2), a 5 mph (8 km/h) breeze, and a relative humidity of 30 percent, as much as 11,500 gph (43.47 m^3/hr) can be evaporated. This sytem is successful, since during the summer evaporation exceeds precipitation in this dry region by about 25 percent. If the relationship were reversed, the system likely would be unsuccessful. This condition is somewhat unique, since in most timber growing areas and their associated manufacturing centers the annual precipitation substantially exceeds the annual evaporation.

Agricultural irrigation is the second wastewater disposal method used in this system. A 50-acre site adjacent to the storage lagoon provides an excellent area for wastewater disposal. A 25-hp (18.64 kW) motor driving a 4-in (10.16 cm) centrifugal pump moves up to 864,000 gpd (3283 m^3/d) of wastewater from the storage lagoon to the fields during the disposal season. This is a fortunate situation, since the vast majority of Boise Cascade facilities do not fit this situation.

Wet log-deck irrigation is the third and primary method of wastewater disposal. Wastewater is taken from the storage lagoon through a 10-in (25.4 cm) pipe to a 6-in (15.24 cm) centrifugal pump driven by a 100-hp (74.5 kW) motor. The pump increases the pressure to about 95 psi (655 kPa) and delivers the wastewater to the log-deck irrigation sprinklers. As the water leaves the pump it is filtered to remove any debris that might clog a sprinkler head.

The 40-acre (161,880 m^2) log deck provides an excellent wastewater disposal site. It not only provides a large evaporation area, but also furnishes the sprinkling water for the log deck. Unfortunately, not all of the 1.8 mgd (6804 m^3/d) of wastewater applied to the log decks evaporates. The balance of the water drains to the return culvert and is recycled through the recycle system.

The last major area of modification necessary to provide this self-contained wastewater disposal system was the elimination of outflows from the log pond. All surface inflows to the pond were intercepted and diverted or eliminated. The French drain dries up the underground springs that had previously fed into the bottom of the pond. The log pond was then no longer a wastewater source.

It has been estimated that the additional annual operational and maintenance costs of the self-contained wastewater disposal system over that of disposing of excess wastewater to rivers and streams will be about $18,000 to $20,000 per year. This cost represents the use of additional power, maintenance pumps, and pipes and dredging.

Case Study: Waste Management at Masonite Hardboard Mills

Hardboard manufacturers use water to convey fiber, clean equipment, scrub air emissions, trim mats, seal vacuum pumps, dry panels, clean fiber, and cool panels. Water is a component of the dynamic force that separates fiber, and water is the vehicle in some of the paints that coat the finished product. Water is essential to the manufacture of wet process hardboard and its use and discharge must be carefully controlled.

An essential step in processing the type of hardboards manufactured at Laurel, Mississippi and Ukiah, California mills involves the use of great quantities of water to wash the fiber to ensure removal of a large portion of the water-soluble extractives found naturally in wood. The most important of these extractives are wood sugars.

The Laurel, Mississippi plant pioneered studies to use wood sugars recovered from fiber washing operations as a source of carbohydrates for animal feed. This early work, performed at Mississippi State College, failed to produce a solution and Masonite utilized the wood sugars to produce alcohol. The alcohol plant at Laurel also did not provide an answer and faced early closure.

In 1950 the Ukiah, California plant opened with a waste disposal system consisting of Vulcan evaporators to reduce the wash water or liquor to 45 percent solids, a sludge burning boiler, and irrigation fields. Subsequently, attempts were made to start a modified activated sludge system. While such a system was recognized as a viable treatment for municipal waste, it was not found to be applicable to industrial effluent with wide variability of loading. BOD loads ranging from 500 to 5000 mg/l kept the treatment system in an upset condition and forced continued use of the sludge burning boiler.

Recognition that use of the wood sugars was a better solution to disposal than discharge caused renewed interest in the production of foodstuff from process water. In the early 1960's this interest led to a pilot plant at Laurel, Mississippi for the production of wood sugar molasses. Success brought about a full-scale production plant at the Laurel site and establishment of a pilot plant for technology transfer at Ukiah.

Transfer technology failed at Ukiah, as it had in earlier attempts to duplicate production equipment. It became necessary, therefore, to establish a new method for producing the desired wood sugar molasses. New studies of the liquor, evaporation methods, and storage and feeding techniques were instigated. Finally, in 1970, a three-stage evaporator plant went into production of the cattle feed supplement Masonex at the Ukiah mill.

The production of Masonex as a byproduct of the manufacture of hardboard is paradoxical, since the manufacture of a readily saleable product is the result of the disposal of a pollutant. Liquors drawn off the fiber washers generally range from 4.5 to 5.5 percent dissolved solids. Evaporation of excess water is accomplished in a multiple-effect process that utilizes three Swenson falling-film evaporators in tandem to raise the solids to approximately 12 percent. Solids are then increased to 45 percent in Vulcan evaporators. Finally a Parkson unit concentrates Masonex to the desired consistency of 60 percent solids. At this point a caustic must be added to ensure safe storage in steel tanks.

Masonex is used as a liquid supplement in prescribed feed mixtures at commercial feed lots. Tests indicate increased palatability of the mixture and faster rate of gain when such a supplement is used.

The final Masonex product from Ukiah differs from that produced at Laurel. Although both products provide identical results under test feedings, the Ukiah product has a much lower viscosity, 700 centipose, while the Laurel product is near 5000 centipose at the same percent solids. The West Coast product also has a shorter storage life. These differences appear to be the result of the use of different wood species at the two mills.

In response to the California Water Quality Control Act, the Ukiah mill developed a plan in 1969 for complete control of the quality and quantity of wastewater discharge to the Russian River. The expansion of the evaporator plant in 1970 and the successful production of the cattle feed supplement was the first step. Operation of the enlarged evaporator permitted Masonite to improve excess process water by reducing its solids content. The evaporative process reduces the quantity and BOD loading of the water to be treated.

From the earliest days of operation, a combina-

tion of factors including wood species and materials handling and disposal systems have permitted Ukiah to operate with a process water system that is essentially closed. Process water used for conveying fiber is circulated through a large tank that acts as a primary clarifier. Accumulated sludge is removed from the tank and returned to the furnish system for the production of hardboard through a process pioneered but found not to be applicable at the Laurel mill.

In 1971 work began again in Ukiah on a biological treatment system. A pilot plant, consisting of Doughboy pools and other unsophisticated equipment, shed some light on the possibility of dividing the waste streams from the mill to allow increased treatment where needed. The pilot biological plant operated approximately 9 months, during which time the design concepts for a proposed treatment plant were evaluated. In 1973 final design of the plan began and a startup date in early 1975 was set to conform with the requirement of the Regional Water Quality Control Board.

The wastewater treatment facility that went into full operation in May 1975 consists of a dual biological treatment system for wastewater streams from the mill. A strong-side stream, consisting of evaporator condensate and chip pile runoff, is treated in an activated sludge system. A weak-side stream consisting of stormwater runoff, cooling, and washdown water is treated in an aerated pond system.

The strong-side stream averages 600 mg/l BOD with very low solids. Following nutrient addition of aqueous ammonia and phosphoric acid, the water enters either of two aeration basins where it is retained for 2½ days. During this period the total suspended solids (TSS) will rise to approximately 2500 mg/l. Wastewater from the aeration basins flows by gravity to a clarifier where a half day of retention will effect a 99 percent or better reduction in BOD while dropping the TSS to near 15 mg/l. The aeration basins receive 50 percent of the flow from these clarifiers as culture. The remaining 50 percent is mixed with the weak-side stream either before or after treatment of the weak-side, depending on the need for further reductions of loading.

The weak-side stream has an average flow of 1.2 mgd (4542 m^3/d) of cooling and washdown water and stormwater runoff. Typical loading of this influent is 125 mg/l BOD and 80 mg/l suspended solids. Floating grease and oils are collected prior to entry into the treatment system by a cable moving across the surface of the influent ditch.

Chlorinated sanitary wastewater is added to the weak-side stream prior to entry into a 9-million-gal (34,068 m^3) aeration pond. If the discharge from the strong-side needs additional treatment, it will be added here also. Water from the aeration pond flows by gravity into an 11-million-gal (41,639 m^3) aeration and settling pond for the remainder of its total 14- to 16-day retention in the weak-side treatment system. During this period, Masonite normally experiences a 70 to 80 percent reduction in BOD and TSS.

The discharge from the weak-side is mixed with discharge from the strong-side, and the treated effluent is recycled to the hardboard mill for reuse as cooling water, vacuum pump seals, and washdown at a rate of over 800 gpm (3.02 m^3/min). Excess water is distributed to managed irrigation fields or discharged to the Russian River during the non-recreation season from October 1 to May 14.

While upset conditions resulting from accidental spills of process water and extreme weather conditions, both drought and deluge, have caused temporary operational difficulties, Masonite's wastewater treatment facility has been able to treat mill effluent continuously beyond levels experienced elsewhere in the industry. The success of this facility is attributed to a unique combination of wood species, manufacturing processes within the mill itself, and seasonal variations in temperature and meteorological conditions, along with the solid research effort that preceded construction.

Case Study: Wastewater Purification at Pacific Wood Treating Corporation

Pacific Wood Treating Corporation uses ultrafiltration and reverse osmosis to purify wastewater for use as boiler feedwater (see Figure 20). As designed, wastewater enters one of three oil-water separators: one for creosote accumulater water, one for pentachlorophenol accumulator water, and one for door drippings and rainwater. Oil and sludge from door drippings and rainwater separator are fed to the sludge tank, while oil from the other two separators is returned to the respective work tanks. Water from the separators is combined and fed to a cartridge type filter for further oil and sludge removal. The filtered water is then fed to an ultrafiltration unit for further oil and solids removal. The concentrated waste from the ultrafiltration unit is fed to the sludge tank. Dissolved solids are removed from the filtered water in a reverse osmosis unit and this concentrate also is fed to the sludge tank. Following removal of dissolved solids the water is fed to the boiler-feed deaerator and then into the boiler.

Pacific Wood Treating Corporation disposes of the waste sludge in a wood-waste-fired boiler which is equipped with a baghouse filter for air pollution control.

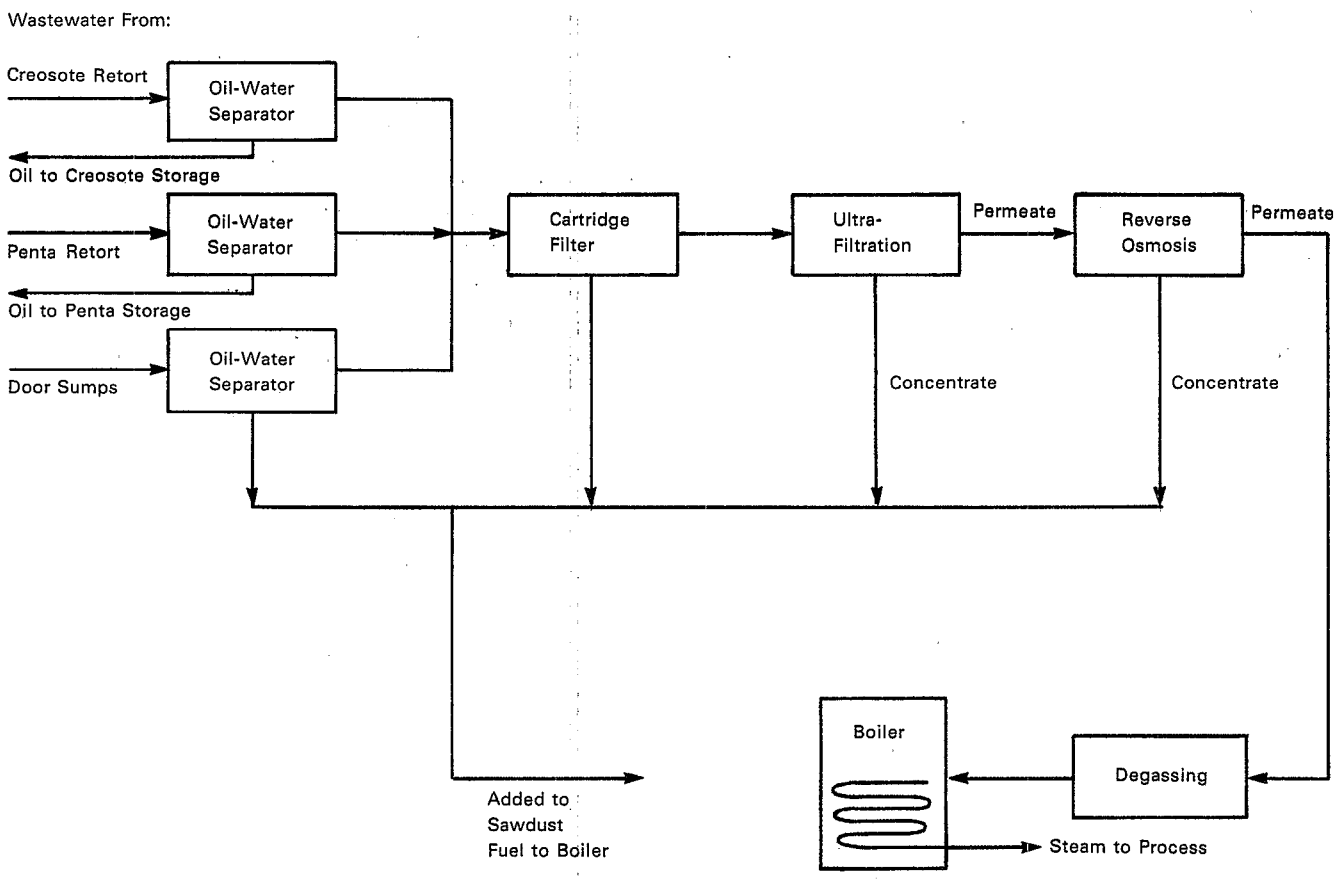

Figure 20. Diagram of the Ultrafiltration-Reverse Osmosis Wastewater Treatment System at Pacific Wood Treating Corp.

To date, little information has been gathered on the operation of the ultrafiltration-reverse osmosis treatment scheme because of fouling and membrane disruption in the unit. To meet immediate zero discharge permit limitations, Pacific Wood Treating has modified its treatment sequence. The first modification was designed to reduce the membrane fouling problem by flocculating the troublesome components from the wastewater. Four pounds of zinc chloride and enough caustic soda to raise the pH to 8 to 9 were added to each 1000 gal (3.785 m^3) of wastewater in a storage tank. The resulting rapidly settling floc is removed from the bottom of the storage tank. The zinc hydroxide floc pulls down iron and copper, as well as organic materials with it. An estimated 90 percent of the fouling materials are removed by the floc. The floc that is removed from the bottom of the tank is incinerated with sludge from other points in the treatment process. Upon incineration the zinc enters the flue gas, where it is helpful in reducing acidity, resulting in longer bag life in the baghouse.

After oil ultrafiltration the wastewater is sent to the boiler feedwater softener where it replaces about half of the boiler water makeup. The result has been longer water softener regeneration cycles, and less boiler blowdown has more than paid for the zinc chloride and caustic chemical costs.

The steam produced by the boiler has a phenolic odor to it. Because of the high pH in the boiler (11.5 to 12) most of the phenols end up in the boiler blowdown. The boiler blowdown is added to the sludge and incinerated. The system has not been operating long enough to produce data on boiler fouling and corrosion problems.

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